NBSIR 81-2289

Preliminary Guidelines for Condition Assessment of Buildings Being Considered for Solar Retrofit

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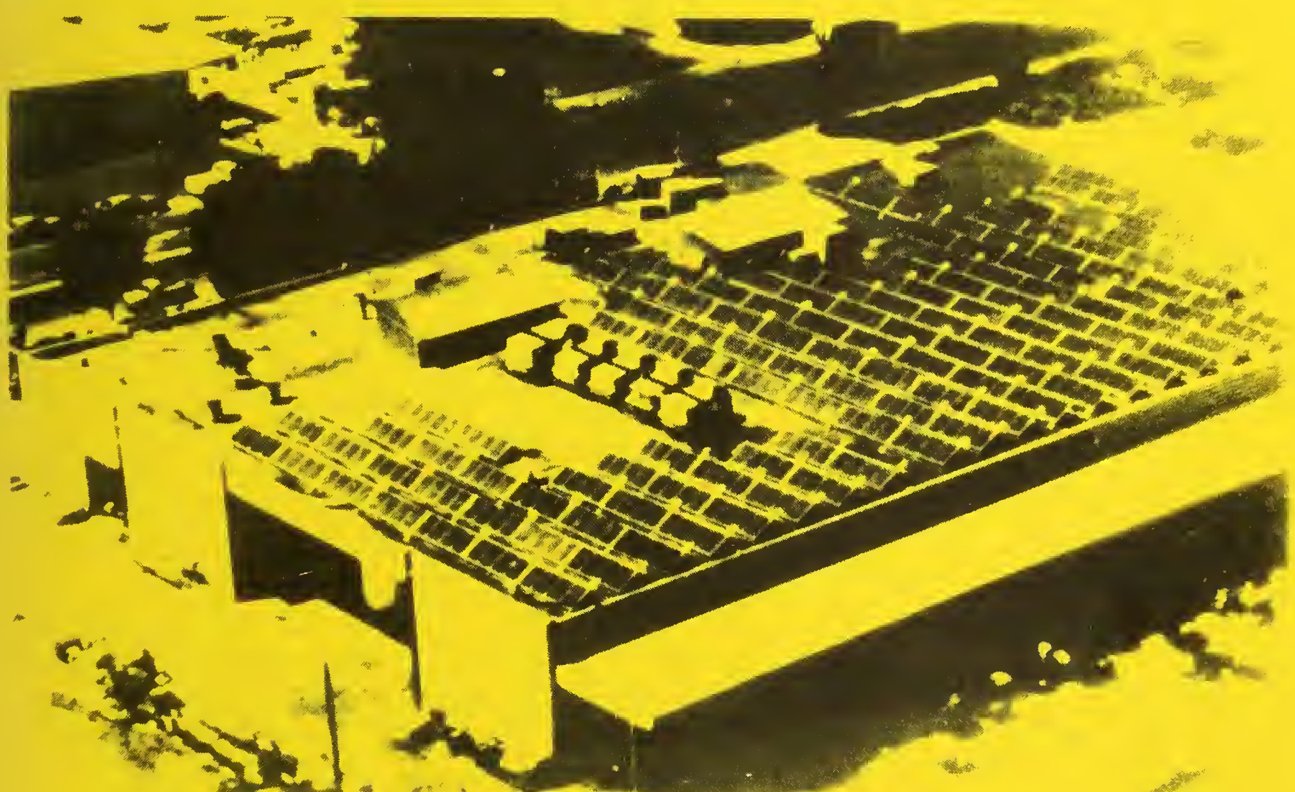

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Washington, DC 20234

Prepared for:

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U.S. DEPARTMENT OF COMMERCE, Malcolm Baldrige, *Secretary*
NATIONAL BUREAU OF STANDARDS, Ernest Ambler, *Director*

ABSTRACT

This preliminary report was developed with the intent of assisting government officials, designers, builders, code officials, and others involved with evaluating the condition of the systems (structural, heating, etc.) of existing buildings in order that the impact of solar modifications on them may be assessed.

The report describes evaluation methods specifically for use with the structural materials of concrete, wood, masonry, and steel, as well as for heating/ventilating/air conditioning (HVAC), plumbing, and electrical systems. Engineering information is presented in two stages: (1) preliminary evaluation methods easily used by the building facilities engineer, and (2) secondary evaluation methods which are more detailed and sophisticated, and which may include information obtained away from the building site.

Comparative tables are provided to aid in making a selection of the evaluation method most appropriate for the particular parameter to be tested. Other tables describe the common problems associated with each material or system and their possible causes as well as the impact they may have on the proposed solar retrofit.

Key words: building rehabilitation; concrete; electrical; evaluation; HVAC; masonry; plumbing; solar; solar retrofit; steel; structural systems; test methods; wood.

ACKNOWLEDGMENTS

The authors would like to extend appreciation to those individuals who generously provided information on many aspects of the evaluation of existing buildings being considered for solar retrofit. Special appreciation is extended to Mr. James G. Gross, Chief, Building Economics and Regulatory Technology Division, Center for Building Technology (CBT), National Bureau of Standards (NBS), for overall direction of the report; Mr. William J. Meese, General Engineer, NBS, for input in the electrical area; Dr. James R. Clifton, Research Chemist, NBS, for input on evaluation of concrete; and Ulesia B. Gray, Editorial Assistant, Word Processing Center, and Mary M. Chaney, Secretary, Rehabilitation Technology Group, CBT, NBS, for outstanding clerical support.

It is with great appreciation, also, that the authors acknowledge the efforts of individuals outside the National Bureau of Standards for their review of the report concerning technical aspects. In particular, appreciation is extended to Dr. V. M. Malhotra, P.E., Head, Construction Materials Section, Department of Energy, Mines and Resources, Canada, for his review and comments on concrete evaluation; Mr. William L. Galligan, Project Leader, Engineering Properties of Wood, Forest Products Laboratory, Forest Service, U.S. Department of Agriculture; Mr. Alan H. Yorkdale, P.E., Director of Engineering and Research, Brick Institute of America; Mr. Peter Jacobs, Systems Analyst, Solar Environmental Engineering Company; and Mr. Scott Heider, P.E, consultant.

PREFACE

The study to develop this report was conducted by the Rehabilitation Technology Group, Building Economics and Regulatory Technology Division, National Bureau of Standards. The report contains a general description of methods currently available for condition assessment of the structural; heating, ventilating, and air conditioning (HVAC); electrical; and plumbing systems of an existing building, in order to determine the feasibility of rehabilitation for solar retrofit.

The intended audience for this report includes government officials, designers, builders, code officials, and others involved with making technical decisions on building rehabilitation as related to solar retrofit. It is not intended for use by nontechnical persons who are unfamiliar with the performance of building materials and basic engineering principles.

The report was developed with funding from the Department of Energy (DoE) as part of the Solar Federal Buildings Program (SFBP) which was developed to stimulate the growth and improve the efficiency of the solar industry as applied to Federal buildings.

This report is not presented as an all-inclusive listing of building condition assessment methods. Additionally, neither NBS nor DoE endorses or claims to have evaluated all of the methods described in this report. It is anticipated that this preliminary report will be updated, and the authors would appreciate comments and recommendations for revisions.

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MOST COMMON SI UNITS AND THEIR
EQUIVALENT VALUES IN
CUSTOMARY UNITS

	INTERNATIONAL (SI) UNIT	CUSTOMARY UNIT	APPROXIMATE CONVERSION	
LENGTH	meter (m)	foot (ft)	1 m	= 3.2804 ft
	millimeter (mm)	inch (in)	1 mm	= 0.0394 in
AREA	square meter (m^2)	square yard (yd^2)	1 m^2	= 1.1960 yd^2
		square foot (ft^2)	1 m^2	= 10.764 ft^2
	square millimeter (mm^2)	square inch (in^2)	1 mm^2	= 1.55×10^{-3} in^2
VOLUME	cubic meter (m^3)	cubic yard (yd^3)	1 m^3	= 1.3080 yd^3
		cubic foot (ft^3)	1 m^3	= 35.315 ft^3
	cubic millimeter (mm^3)	cubic inch (in^3)	1 mm^3	= 61.024×10^{-6} in^3
CAPACITY	liter (L)	gallon (gal)	1 L	= 0.2642 gal
VELOCITY, SPEED	meter per second (m/s)	foot per second (ft/s)	1 m/s	= 3.2808 ft/s
	kilometer per hour (km/h)	mile per hour (mile/h or m.p.h)	1 km/h	= 0.6214 mile/h
ACCELLERATION	meter per second squared (m/s^2)	foot per second squared (ft/s^2)	1 m/s^2	= 3.2808 ft/s^2
MASS	metric ton (t)	ton (2000 lb)	1 t	= 1.1023 ton
	kilogram (kg)	pound (lb)	1 kg	= 2.2046 lb
	gram (g)	ounce (oz)	1 g	= 0.0353 oz
DENSITY	metric ton per cubic meter (t/m^3)	ton per cubic yard (ton/yd^3)	1 t/m^3	= 0.8428 ton/yd^3
	kilogram per cubic meter (kg/m^3)	pound per cubic foot (lb/ft^3)	1 kg/m^3	= 0.0624 lb/ft^3
FORCE	kilonewton (kN)	ton-force (tonf)	1 kN	= 0.1124 tonf
		kip (1000 lbf)	1 kN	= 0.2248 kip
	newton (N)	pound-force (lbf)	1 N	= 0.7376 lbf
MOMENT OF FORCE, TORQUE	kilonewton meter (kN·m)	ton-force foot (tonf·ft)	1 kN·m	= 0.3688 tonf/ft
	newton meter (N·m)	pound-force inch (lbf·in)	1 N·m	= 8.8508 lbf·in
PRESSURE, STRESS	megapascal (MPa)	ton-force per square inch ($tonf/in^2$)	1 MPa	= 0.0725 $tonf/in^2$
	kilopascal (kPa)	ton-force per square foot ($tonf/ft^2$)	1 kPa	= 10.443 $tonf/ft^2$
		pound-force per square inch(lbf/in^2)	1 kPa	= 145.04 lbf/in^2
	pascal (Pa)	pound-force per square foot(lbf/ft^2)	1 Pa	= 20.885 lbf/ft^2
WORK, ENERGY, QUANTITY OF HEAT	kilojoule (kJ)	British thermal unit (Btu)	1 kJ	= 0.9478 Btu
	joule (J)	foot pound-force (ft·lbf)	1 J	= 0.7376 ft·lbf
COEFFICIENT OF HEAT TRANSFER (U-Value)	watt per square meter kelvin ($W/m^2 \cdot K$)	Btu per square foot hour degree Fahrenheit ($Btu/ft^2 \cdot h \cdot °F$)	1 $W/(m^2 \cdot K)$ =	0.1761 $Btu/(ft^2 \cdot h \cdot °F)$
THERMAL CONDUCTIVITY (k-Value)	watt per meter kelvin (W/m·K)	Btu per foot hour degree Fahrenheit (Btu/ft·h·°F)	1 W/(m·K) =	0.5778 Btu/(ft·h·°F)

NOTES: (1) The above conversion factors are shown to four significant digits, where appropriate.

(2) Unprefixed SI units are underlined. (The kilogram, although prefixed, is an SI base unit.)

REFERENCES: NBS Metric Guidelines, LC1056, August 1977;
NBS Special Publication 330, "The International System of Units (SI);"
NBS Technical Note 938, "Recommended Practice for the Use of Metric (SI) Units in Building Design and Construction;"
ASTM Standard E621-78, "Standard Practice for the Use of Metric (SI) Units in Building Design and Construction;"
ANSI Z210-1976, "American National Standard for Metric Practice;" ASTM E380-76, or IEEE Std. 268-1976.

1. INTRODUCTION

1.1 PURPOSE OF THE REPORT

This preliminary report was prepared to show Federal agencies what evaluation methods are available to determine whether buildings in their inventory are suitable for solar energy retrofit. It describes methods for developing the engineering information needed to determine whether the building and its mechanical/electrical systems can be retrofitted for solar energy under the Solar Federal Buildings Program (SFBP).

The report is intended to be used by the agency's facilities engineer to conduct on-site and/or off-site investigations of the building structure and its systems. Engineering information is developed in two stages: (1) preliminary information derived from reasonably unsophisticated procedures, and (2) secondary information derived from more detailed or sophisticated procedures. The ultimate decision to recommend solar retrofit should be made by the facilities engineer and associated consultants.

1.2 AUTHORIZATION

Funding for the report was provided by the Department of Energy (DoE) as part of the Solar Federal Buildings Program (SFBP). This multi-year program is designed to stimulate the growth and improve the efficiency of the solar industry by providing funds to Federal agencies for the design, acquisition, construction, and installation of commercially applicable solar domestic hot water, heating, cooling, and process systems in new and existing Federal buildings. The SFBP was authorized under Title V, Part 2 of the National Energy Conservation Policy Act, enacted on November 2, 1978 (PL 95-619). Program implementation began with the approval of the procedures published in the October 19, 1979, Federal Register (Vol. 44, No. 204), and it became fully operational with the publication of the Federal Energy Management and Planning Programs (FEMP) Final Rule in the January 23, 1980, Federal Register.

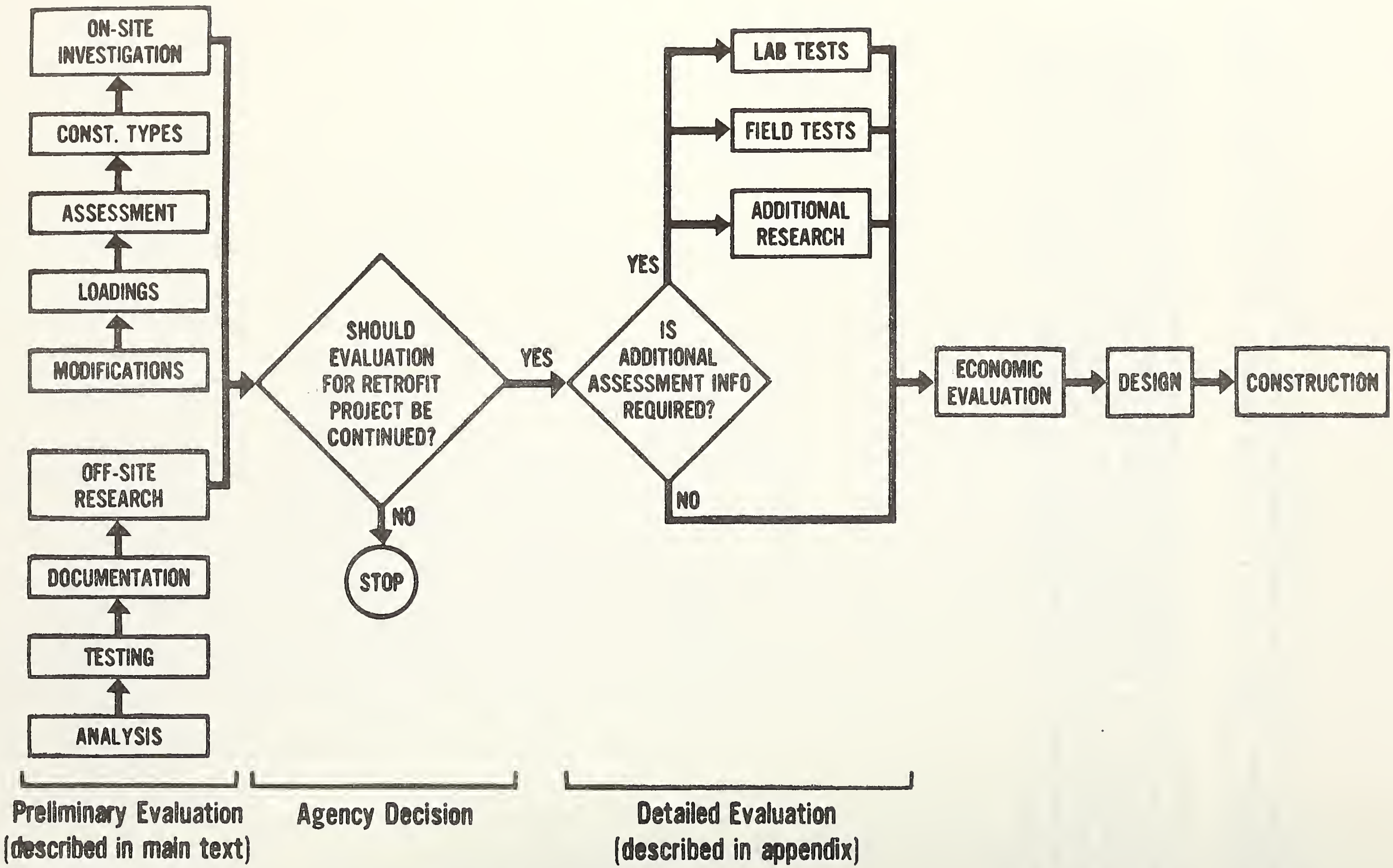
If a Federal agency plans to retrofit a building for solar energy under the SFBP, it must submit to the DoE a proposal for each project. Each proposal must contain: (1) general project information; (2) site and building description; (3) building load information; (4) solar system description; and (5) auxiliary (or backup) system information, including the method for selecting the solar design proposed. The guidelines presented in this report will be useful in preparing the required information. The October 19, 1979, Federal Register contains more specific information on the subject.

1.3 NEED FOR ANALYSIS

The rapid rise of oil prices and the apparent limit of known sources has resulted in a greater concern for efficient Federal utilization of available energy sources. Since solar energy is a viable supplement to conventional energy sources, Federal agencies are expected to consider its use. However, the cost benefits of solar energy must be considered against other available energy sources. For example, solar energy is generally considered to be

- Electrical: Additional electrically operated equipment such as blowers, pumps, water chillers or heat pumps will require the modificatioon of the existing power supply system, including possible additional power capacity, wiring and controls.

Figure 1 provides an overview of the sequence recommended for determining whether a particular building and its systems can support a solar retrofit. If solar retrofit is determined to be feasible, further economic evaluation may be required to be provided by others. The information provided by the engineering evaluation will be useful to the retrofit designer when a decision has been made to proceed, although the designer ultimately will have to determine exactly what evaluation information is required for a complete design.



ENGINEERING EVALUATION PLAN

Figure 1

2. PRELIMINARY EVALUATION METHODS

2.1 ON-SITE INVESTIGATION

Visual inspection of a building and simple assessment procedures will provide most of the information required to determine the condition and capability of the building and its systems. Most defects (such as missing components, cracks, corrosion, misalignment, etc.) affecting solar retrofit can be detected visually.

The on-site inspection procedure generally includes:

1) General site inspection.
2) Gathering of existing documents (plans, specifications, etc.).
3) Survey of building condition, including sketches and photographs.
4) Gathering of specimens for evaluation.
5) Simple field tests.
6) Interviews with owners/occupants.

The information obtained during inspection should include:

1) A list of materials, components, and systems existing in the building (including structural; heating, ventilating, and air conditioning (HVAC); plumbing; and electrical items).

2) Condition and capacity of existing components (e.g., extent of deterioration of concrete structural members; nameplate data for fans and pumps; etc.);

3) Actual occupancy related loads (structural, heating, plumbing, etc.) to which the building is subjected.

To organize the accumulated data during the on-site investigation, a project dossier should be established consisting of a project notebook and a file containing all notes, correspondence, and documents (as well as collected reference material) concerning the prospective solar retrofit project.

2.1.1 Project Notebook and Forms

The project notebook should contain the following information (typical forms are shown in appendix A).

1) General Building Information (See sample form A-1)

Form A-1 is designed to provide broad administrative and technical information relative to the structure under investigation. More detailed data is collected on additional forms described below.

2) Component/Assembly Information (See sample form A-2)

Form A-2 is designed to provide detailed information relative to the physical condition of specific components and assemblies of the various building systems

(structural, plumbing, HVAC, and electrical). Data should be cross-referenced to other forms.

3) Journal Entry List (See sample form A-3)

Form A-3 is used to provide a record of all important agreements, decisions or actions made by the facilities engineer, or his staff. If the remarks concerning the entry are extensive, then an attachment should be made, noted under the remarks and filed in the dossier with the Journal Entry number clearly marked.

4) Contact List (See sample form A-4)

Form A-4 is designed for the orderly collection of information from people contacted in the course of the preliminary investigation. For example, this form can be used to identify all past or present occupants of the building, the owner or manager of the building, the architect, engineers, etc.

5) Document List (See sample form A-5)

Form A-5 is used to complete information on plans, specifications, etc., which might aid in the investigation of the building.

6) Photograph List (See sample form A-6)

Form A-6 provides a record of all photographs of the building and adjacent areas taken or collected by project staff.

7) Sketch List (See sample form A-7)

Form A-7 provides for orderly collection of sketches relative to the building or component condition. It should be cross-referenced to the photograph list.

8) Specimen List (See sample form A-8)

Form A-8 provides a record of samples removed from the building in the course of the preliminary investigation. The sketches of the sample locations along with photographs and sketches of the samples themselves should be entered on forms A-6 and A-7.

2.1.2 Project Files

The project files should include the following items:

1) General Correspondence
2) Journal Entry Supplements
3) Collected Documents and Citations
4) Photographs and Negatives
5) Field Reports and Sketches
6) Test Results

7) Analytical Studies
8) Evaluation Report

2.1.3 Field Inspection Equipment

Appendix B contains a list of items which would be useful in conducting an on-site investigation.

2.2 OFF-SITE INVESTIGATIONS

Additional information also is needed which is obtained away from the building site. This information compliments the on-site investigation and provides a complete picture of a building and its potential for solar retrofit. It consists of: (1) analyses of the building systems, (2) simple laboratory tests of specimens removed from the building, and (3) additional building documents. The latter includes drawings and specifications, construction records, operation and maintenance records, records of alterations made to the buildings and systems, information on material properties, and records describing site conditions. Sources of this information are the Federal agency headquarters, the building facilities engineer, the building contractor, the surveying contractor, and the building designer. Appendix C contains a more complete list of such information and potential sources.

Existing documents should not be used by themselves to evaluate a building since frequently they may not reflect actual conditions. Therefore, an on-site investigation of the as-built conditions always is recommended in conjunction with a review of existing documents.

Data obtained off-site may be handled and filed in the same manner as is described above for on-site data.

2.3 DESTRUCTIVE VS. NONDESTRUCTIVE EVALUATION

Throughout the structural portions of this report, evaluation methods will be referred to as nondestructive or destructive. A definition of each is provided below along with advantages and limitations.

A. Nondestructive Evaluation is the process of inspecting, evaluating, and/or measuring the performance or properties of materials or systems in a manner which will not change, damage, or destroy the properties or affect the service life of the specimens [3].

1) Advantages

- Can be performed in-situ with little or no damage to the specimen.
- Different tests can be used on the same test member simultaneously or sequentially.
- The same test can be repeated on the same test member.

- The cumulative effect of the time in service of the test member can be measured directly.

- Little or no preparation is required to be performed on the test member.

- The equipment often is portable for in-situ use.

- Labor costs usually are low, especially for repetitive testing of similar test members.

2) Limitations

- Sometimes interpretation of the test results must be accomplished by skilled, experienced technicians.

- In the absence of proven correlation, the meaning and significance of the test results could be interpreted differently by various evaluators.

- Some nondestructive tests require very sophisticated and expensive testing equipment.

- Often only qualitative or comparative measurements of the properties of the test sample can be made.

B. <u>Destructive Evaluation</u> is the process of inspecting, evaluating, and/or measuring the properties of materials or systems in a manner which can change, damage, or destroy the properties or affect the service life of the test specimen [3].

1) Advantages

- Measurements are direct and usually reliable.

- Measurements are quantitative and usually are valuable for determining the existing properties of the test member.

- Skilled technicians usually are not required to interpret test results.

- There usually is a direct correlation between test results and the in-situ properties of the test sample - thus leaving little to interpretation among various evaluators.

2) Limitations

- Applicable only to a test sample. Further proof may be required that the test sample is representative of the rest of the building members.

- Tested members are damaged or their service life is affected.
- Often it is not possible to repeat tests on the same member of the building because of the destructiveness of the test.
- The cumulative effect of the time in service of the test member cannot be measured directly, but can only be inferred from tests made on the members at different lengths of time.
- Difficult to use in-situ.
- Pre-test preparation work usually is required.
- Often the equipment and manpower costs are high.

3. GUIDELINES FOR STRUCTURAL SYSTEMS

3.1 GENERAL CONSIDERATIONS

3.1.1 Structural Condition Assessment

The assessment of existing structural components should include strength, stiffness, and stability considerations. On-site inspection of a building can provide a great deal of information relative to these properties.

3.1.2 Structural Loadings

The addition of solar components to an existing building often will change structural loadings. These changes could be in the form of additional dead loads from collectors, absorption chillers, water storage tanks, or rock beds; dynamic or vibrational loads from rotating or reciprocating equipment; or changes in live load caused by the rehabilitation of the building (e.g., change in occupancy). Tables 1, 2 and 3 provide guidance on the types of such loading to expect. Not only should new loading be considered but modifications to the structural system should be analyzed. Examples include the cutting of chases in existing floors, walls, or roof systems for the passage of mechanical/electrical support systems, and the modification to an existing building for passive solar benefits where large openings may be added to the building envelope. Good engineering practice and careful assessment should be used to evaluate the impact of revised loadings.

3.1.3 Environmental Changes

The addition of solar components can create serious problems for stuctural systems by changing the ambient moisture and temperature conditions. Minor structural accommodations (e.g., cracks in plaster) may occur during the time it takes for the building to adapt to the proposed new conditions. The preliminary evaluation should attempt to anticipate these problems and to assess the degree of severity or significance of such problems on the building.

3.1.4 Date of Building Construction

Data relative to the properties of materials in an existing building can be estimated if the date of construction is known. Approximate strength values generally are sufficient for analytical purposes in assessing structural characteristics. The date of a building can provide clues relative to design codes, engineering standards, construction techniques and materials used, and hence the structural performance to be expected. For example, the design yield strength of structural steel has changed considerably over the

TABLE 1

LOADS FROM ROOF COVERINGS[1/]

	Pa x 10^{-3}	lbf/ft^2
Asbestos Shingles	120	4
Asphalt Shingles	95	2
Copper or Tin	48	1
Corrugated Iron	96	2
Clay Tile (for mortar add 10 lb.):		
2" Book Tile	574	12
3" Book Tile	958	20
Roman	574	12
Spanish	919	19
Ludowici or Shingle	479	10
Cement Tile	766	16
Composition:		
Three-ply ready roofing	48	1
Four-ply felt and gravel	263	5.5
Five-ply felt and gravel	287	6
Wood-Sheathing, per inch thickness	144	3
Slate, 3/16 inch	335	7
Slate, 1/4 inch	479	10
Skylight, metal frame 3/8" wire glass	383	8
Wood shingles	144	3
Insulation, per inch thickness	48	1
Gypsum Plant, 2 inch	574	12
Metal Deck (1 1/2" with ribs 6" o.c.)	120	2.5

[1/] Roof loads for typical flat plate collectors and supports are in the range of 0.5-0.7 Pa (10-15 lbf/ft^2).

TABLE 2 [7]

SIZE AND WEIGHT OF TYPICAL CHILLERS

Derated Capacity	Maximum Rated Capacity	Dimensions L x W x H	Wt (lb) (wet)	Average Floor Load (psf) (kPa)	(lbf/ft^2)
30t	100t	11' x 5' x 7'	11,260	9.8	205
60t	200t	14' x 5' x 8'	16,350	11.2	234
105t	350t	19' x 6 x 8'	24,700	10.4	217
180t	600t	22' x 7' x 9'	35,250	11.0	229
285t	950t	22' x 8' x 11'	57,400	15.6	326
375t	1,250t	25' x 10' x 12'	85,700	16.4	343

TABLE 3 [7]

WEIGHT OF TYPICAL STORAGE TANKS[1/]

Capacity		Weight Including Water			
		unpressurized		pressurized	
litres	gal	kg	lb	kg	lb
1,893	500	2,073	4,570	2,499	5,510
3,785	1,000	4,182	9,219	4,951	10,915
9,465	12,500	6,187	13,640	7,317	15,132

1/ Storage tanks are sized commonly at 3.8-7.6 litres (1-2 gallons) of storage per 0.1 m^2 (ft^2) of collector area.

years. In lieu of costly testing of steel in an existing building it may be appropriate to assume conservative values based on the following relationship:

Date	Yield Point [4,5,6] (MPa)	(lbf/in^2)
Constructed prior to 1905	f_y = 172.37	25,000 psi
Constructed 1905-1932	f_y = 206.84	30,000 psi
Constructed 1933-1963	f_y = 227.53	33,000 psi
Constructed after 1963	f_y = 248.21	36,000 psi

3.2 GENERAL INSPECTION GUIDELINES -- STRUCTURAL COMPONENTS

As shown in figure 1 and discussed in section 2.1, the on-site investigation consists of a general site examination and a building condition survey. While the major emphasis should be on the assessment of structural components which may be affected by the solar retrofit, it is necessary to make an overall review of the condition of the whole building. This is especially significant where additional structural loadings or modifications are anticipated. The following general inspection guidelines will be useful in this assessment.

3.2.1 Foundations

The foundation is one of the most important structural components to assess. It should be anticipated that such things as added loads or changes in soil drainage patterns around the building can impact the building foundation detrimentally. References [8, 9, 10] provide the following guidelines:

(a) Check for soft and crumbling mortar in foundation walls. This could be serious if it is associated with any signs of sag in the structure.

(b) Foundation wall cracks usually are diagonal, starting from the top, the bottom, or the end of the wall. If the cracks do not extend to at least one edge of the wall, they probably are not caused by foundation problems, but are more likely due to other structural problems (see table 5 and table 9).

(c) Be sure the ground slopes away from the foundation wall so that rain water drains off properly.

(d) Downspouts should have splash blocks to divert water away from the building.

(e) Although it usually is difficult to determine the condition of a footing without excavating the foundation, structurally unsound footings usually will be indicated either by large cracks or by settlement in the foundation walls.

(f) Leaning, buckling, or bulging foundation or bearing walls may be the result of a number of hidden or interacting problems. For

example, they may be the result of differential building settlement or failure of a structural beam or girder.

(g) If new heavy loads are to be added to the existing foundation, it will be necessary to check it for ability to carry the new loads. If details of the foundation design and the soil bearing value cannot be determined from existing drawings and reports of subsurface soil investigations, it may be necessary to: (1) excavate adjacent to an outside wall to determine the type of existing foundation and (2) conduct a subsurface soil investigation (soil borings). Results from the subsurface soil investigation can be used to support the need for new foundations under heavy loads or to prove the adequacy of existing foundations.

3.2.2 Exterior Walls

(a) Check for plumbness. Use a plumb line. Out of plumb exterior walls can be a sign of serious foundation problems.

(b) Sight along wall for any sign of bulges which could indicate major structural problems.

(c) Doors that do not line up squarely in their frames can be another sign of possible foundation problems.

(d) Check that all joints between dissimilar materials (e.g., wood and masonry joints) around door frames, window frames, and decorative trim are tightly caulked or properly flashed to prevent water penetration.

(e) Check for vertical or zig-zag cracks through bricks and mortar that can be an indication of uneven settling.

(f) Check that mortar joints are sound (not soft and crumbling) and that no bricks are missing or loose.

(g) Look for any sign of spalling, cracking, or crumbling of exterior stonework.

(h) Check for any loose, cracked, or missing clapboards that could admit water into the building.

(i) Identify any loose, thin, or badly weathered siding or shingles which are an open invitation to water and rot.

(j) Check for rotting of the siding or erosion of the exposed portion of the cellar or basement walls which often results from missing or leaking gutters.

3.2.3 Roof

(a) Inspect for sagging condition of the roof. Especially attempt to examine the rafters, purlins, collar beams, and ridge boards wherever possible. Where applicable check the condition of the roof boards from inside the attic.

(b) Look for evidences of a leaking roof. This condition will be indicated by loose plaster or peeling or stained paint and wall paper.

(c) Check condition of gutters and rain leaders around the entire building to insure proper drainage of water. Evidences of the lack of gutters (or leaking gutters) are: (1) rotting of the siding, or (2) erosion of the exposed portion of the cellar or basement walls.

(d) All existing dead and live loads on the roof should be summed to determine the accumulative existing loads and to determine whether the additional load of 0.5 to 0.7 kPa (10 to 15 lbf/ft^2) imposed by typical solar components can be supported by the structure. The design capacity should be checked with respect to expected snow, ice, and wind loads for the local geographical area, as well as the dead loads of the roofing materials.

(e) If the existing roof is composed of a steel deck on steel joists, and new heavy concentrated dead loads are to be imposed on the deck by solar equipment, be sure the joists have been designed for twice the static operating weight of the equipment. Be sure there is enough room to reinforce the top chords of the joists for any new concentrated loads which may be applied between panel points. Since any new concentrated loads which must be applied to the bottom chords will have to occur at panel points, it will be necessary to check that access to these points is possible. Existing joists should be checked to be sure they can support newly imposed loads without exceeding a maximum deflection of 1/360 x span.

(f) Be sure that existing conditions will accommodate roof mounted equipment supports which will permit easy access for roof maintenance.

3.2.4 Attic

(a) Look for signs of leaks (e.g., dark water stains) on the underside of the roof, especially around chimneys, valleys, and eaves.

(b) Check for proper ventilation, especially for signs of mildew on underside of roof boards.

3.2.5 Interior Spaces

(a) Look for signs of damp plaster which may indicate the existence of leaks from the roof or internal pipes.

(b) Check for any loose or spongy plaster in walls or ceilings which could indicate the existence of leaks.

(c) Substantial vibration (bounce) of stairways; or gaps between treads, risers, and side stringers of stairs may indicate structural problems.

(d) Check to see if the flooring is in good condition (flooring covered with linoleum, carpet, etc., can harbor unseen problems).

(e) See if floors have a pronounced sag or tilt. A simple test can be performed with a marble (to see if it rolls) or with a level. A sag or tilt could indicate normal settling, or structural problems.

(f) Jump on floors to see whether the floors vibrate or the windows rattle (this would indicate inadequate support caused by undersized beams, inadequate bridging, cracked joists, or rotted support post, etc.).

(g) Look for signs of water leakage around window frames.

(h) If outside light can be seen through openings around window rails and door jams, the condition of the support girders, posts, and studs should be questioned. This condition often is evidence that some of these members may be termite infested or rotted and may be causing the outside wall to sag.

(i) Wherever possible, new columns or equipment supports should be placed directly over existing columns. Therefore, the interior of the building should be inspected to determine whether there are any conditions which would prevent this from being accomplished.

3.2.6 Basement

(a) Probe the sills (wood beams at the top of the foundation walls) with a penknife, awl, or ice pick for signs of rot or termites.

(b) If the mortar between bricks or concrete blocks in foundation walls is heavily eroded (or if other evidences of erosion of the exposed portion of the basement wall exist) check for missing or leaking gutters.

(c) Check for any signs of dampness on the underside of floors around pipes. If left uncorrected, this can cause wood rot.

(d) Signs to look for which warn of probable periodic flooding are: rust spots, efflorescence or mildew on walls, and material stored on top of bricks or boxes to raise it above floor level.

(e) Look for sagging floors, rotted support posts, or jury-rigged props to shore up weak flooring.

(f) Check for general condition of the plumbing (e.g., patches on waste pipes indicate advanced age or structural movement).

3.3 CONCRETE SYSTEMS

Since concrete came into general use as a building material in the latter part of the nineteenth century, many existing buildings currently being considered for solar retrofit require application of concrete condition assessment techniques. Figure 2 summarizes the available techniques for condition assessment including visual techniques and the more complicated test procedures. The remainder of this section is concerned with visual inspection guidelines while the more detailed procedures are discussed in appendix D.1.

3.3.1 Preliminary Evaluation of Concrete Systems

Generally, visual/optical inspection is the most satisfactory, least expensive, and most commonly used method for determining the shape and dimensions of concrete components and for preliminary detection of surface flaws (such as cracks, roughness, scratches, discoloration, etc.). It can be performed with or without the use of optical aids (such as low-power magnifiers). Defects such as missing components, cracks, erosion, corrosion, and misaligned joints, often can be detected with the naked eye. With the use of five to ten power magnifiers, even surface flaws as small as a few microns wide can be detected. Table 4 summarizes visual inspection techniques for concrete.

The most obvious advantage of using the visual method to evaluate surface flaws in concrete is that it is inexpensive and requires no special equipment. However, the visual inspection method can be time consuming and is completely dependent upon the visual acuity, experience, and training of the inspector. It should be understood that no subsurface information can be obtained using this technique and that, even for surface conditions, a correlation already must have been established between the surface conditions and serviceability of the concrete.

During the visual/optical inspection, the following significant structural aspects should be checked or considered:

A. Concrete foundation cracks which are diagonal, starting from the top, the bottom, or the end of the wall. If the cracks do not extend to at least one edge of the wall, they probably are not caused by foundation problems, but are more likely due to other structural problems. It is important to determine the cause of these problems and to remedy the problem because the addition of retrofit solar equipment loads on the building could aggravate the problem further.

B. When new heavy loads are expected to be added to the existing concrete foundation, it will be necessary to check it for structural adequacy. If

details of the concrete foundation design and the soil bearing value cannot be determined from existing drawings and reports of subsurface soil investigations, it may be necessary to: 1) excavate adjacent to an outside wall to determine the type of existing foundation and 2) conduct a subsurface soil investigation (soil borings). Results from the subsurface soil investigation can be used to support the need for new foundations under heavy loads or to prove the adequacy of existing foundations.

C. All existing dead and live loads on the concrete roof structure should be summed to determine the accumulative existing loads and to determine whether the additional loads imposed by the retrofit solar components can be supported by the existing concrete structure. The design capacity of the affected components of the concrete structure should be checked with respect to expected snow, ice, and wind loads for the local geographical area, as well as the dead loads of the roofing materials.

D. Wherever possible, new columns or equipment supports should be placed directly over existing columns. Therefore, the interior of the building should be inspected to determine whether there are any conditions which could prevent this from being accomplished.

3.3.2 Concrete Problems and Potential Impact on Solar Retrofit

A checklist (table 5) can be used to assist in determining what problems exist in a concrete structure and to make a preliminary determination of the impact that the problem may have on the solar retrofit. If it is determined that a more complete understanding of the nature or cause of the problem is necessary, further reference is given in the table to a more detailed description in appendix D.1.

CONCRETE TEST METHODS AND PARAMETERS

	NONDESTRUCTIVE TESTS																	DESTRUCTIVE TESTS	
PARAMETERS	Visual-Optical	Rebound	Pullout	Penetration	Dynamic	Electrical	Magnetic	Load	Acoustic Emission	Acoustic Impact	Ultrasonics	Radiographic	Microwave Absorption	Neutron Moisture Gage	Neutron Activation	Radar	Infrared	Core Drilling	Petrography
Dimensional Characteristics																			
Thickness of Slabs	●					●					●	●				●		●	
Size and location of reinforcing and other electrically conductive components						●	●					●	●			●		●	
Quality and Strength Characteristics																			
Quality of Concrete	●	●		●	●						●	●	●					●	●
Quality of Aggregate	●																	●	●
Uniformity	●	●		●	●						●	●						●	●
Variable Compaction											●	●						●	●
Compressive Strength		●	●	●	●						●							●	
Moisture Content						●							●	●					
Cement Content															●			●	●
Density and Internal Structure of Concrete											●	●		●				●	●
Modulus of Elasticity					●			●		●	●								
Condition of Reinforcing	●					●												●	●
Flaws																			
Surface Flaws	●	●							●		●							●	●
Internal Flaws (Voids, cracks, etc.)	●								●	●	●	●					●	●	●
Voids in grouting of post-tensioned prestressed concrete												●							
Deficiencies in joints	●																		
Substratum Voids																●			
Load Distribution and Stress/Strain																			
Load distribution and strain as detected by surface distortion patterns	●																		
Bonding Stress												●							
Failures Under Stress								●											
Differential Structural Movements	●																		

FIGURE 2

TABLE 4. TEST METHODS FOR CONCRETE

METHODS	CAPABILITIES	DEGREE OF SENSITIVITY	APPLICATIONS	ADVANTAGES	LIMITATIONS
VISUAL/ OPTICAL Visual Inspection	Detection of surface flaws	Detection of cracks 2-3 microns wide on a smooth surface (smaller with a handheld magnifier).	Concrete samples or in-situ concrete structural components.	Inexpensive because no special or power equipment is needed. Can yield defects not detectable by other methods.	Only surface information is given. Relationship between surface appearance and condition of total sample must be determined.
Surveying, Vertical and Horizontal Movement	Measures diffferential movements with time.	Structural movement may be detected within the precision of the surveying equipment.	Long-term observations to determine critical movements of concrete	Cyclical relationships between deformation and temperature or load can be derived.	Immediate data interpretations cannot be made because of the long-term, cyclical observation periods. A trained surveyor is necessary for data collection and evaluation.
Joint Survey	Checks for a variety of joint conditions which may indicate problems with concrete, such as spalling; D-cracks; absence, excesses and condition of joint fillers; seepage; and chemical attack.	Depends upon the manual measuring device used (calipers, etc.).	Expansion, contraction or construction joints in concrete.	An initial step of a more indepth investigation of concrete problems. Inexpensive because survey is limited to visual inspection and manual measurements.	This method is most applicable to foundation walls and slabs. A trained evaluator is necessary for data collection and evaluation.
Fiber Optics	Detects internal cracks, voids, or flaws if path to surface is available.	Working length of 30 to 1330 mm, depending on equipment used.	Can be used to look into cracks or areas where cores have been removed.	Clear, high-resolution image or remote inspection subjects.	Many boreholes are required to give adequate success. Expensive.

TABLE 5. PRELIMINARY ASSESSMENT CHECKLIST (CONCRETE)

Problems	Does Problem Exist? Yes	No	Possible Causes to be Considered	Impact on Solar Retrofit
1. Separation plane under steel reinforcement			Heavy, closely spaced reinforcement causes aggregates to accumulate at re-bar level during settlement at the time of pour.	Separation plane allows place for corrosion of re-bars to start. Also encourages freeze-thaw action from intruded water. Correction is difficult-usually impossible. Affected member may need replacing.
2. Surface cracks directly over steel reinforcement (with or without spalling)			1) Settlement of aggregates during time of initial set. 2) Corrosion of the reinforcement is suspect if spalling has occurred.	If cracks are hairline, there is no problem. Large cracks can encourage corrosion of re-bars and freeze-thaw damage. Cut out (V-notch) and patch cracks before loading with solar equipment.
3. Surface cracks at areas of depression in slab.			Subgrade settlement during concrete pour.	Usually none. Cosmetic patching may be all that is necessary unless crack is large enough to admit water. V-notch and patch large cracks to prevent re-bar corrosion and structural degradation.
4. Surface cracks in slabs - general.			Vibration from construction equipment (pile drivers, blasting operations, etc.)	Assessment of strength of of structural member should be made to determine allowable loads.
5. External wall cracks in variable direction			Shrinkage of concrete from drying or from temperature stresses.	Only important if cracks are large enough to admit water which could corrode reinforcing or cause freeze-thaw damage.
6. Cracks associated with swelling and spalling.			Chemical attack or absorption of moisture.	Concrete may be too porous and may require sealing before covering or loading with solar equipment. Chemical attack by acids may have to be stopped or counteracted.
7. Cracks on bottom of floor slab.			Live load causing deflection in excess of allowable 1/240 to 1/360 x floor span.	Live load capacity of floor already could be exceeded - thus prohibiting any further additional solar equipment loads without strengthening the structural slab.

TABLE 5. PRELIMINARY ASSESSMENT CHECKLIST (CONCRETE) (CONTINUED)

Problems	Does Problem Exist? Yes	No	Possible Causes to be Considered	Impact on Solar Retrofit
8. Spalling in foundations for machinery.			Vibrational loads from the machinery.	None.
9. Spalling in piles.			Shock of driving process.	If spall exposes reinforcing, the reinforcing could corrode and weaken foundation of building.
10. Spalling in pier structures.			Impact of berthing marine vessels.	None - unless pier will be used to support solar equipment. This is a highly unlikely situation.
11. Spalling in line with reinforcing.			Corrosion of reinforcing (from stray electrical currents, chemical attack, or electrolytic action).	Elimination of cause of corrosion and correction of damage will be necessary if load of solar equipment bears on the affected structural concrete member.
12. Disintegration or crumbling away of the matrix of the concrete.			Chemical attack.	If load of solar equipment bears on affected concrete member, the reactive agent should be neutralized or leached out before repairing or covering up the affected area. Damaged area may have to be cut out and replaced with patch material designed to resist the responsible agent.
13. Erosion (abrasion), usually on top of floor slabs, and at surf zone of waterfront structures.			Wheeled vehicular traffic, pedestrians, wave action.	No impact unless structure is being used to support solar equipment. If the erosion has exposed reinforcing, it should be repaired.
14. Deterioration at areas of abrupt section changes, reentrant corners, expansion joints, etc. (e.g., granolithic dusting, cold joint, lifting of concrete screed).			Improper design.	Requires correction only if the member is affected by new solar equipment loads.

3.4 WOOD SYSTEMS

3.4.1 General

The practice of evaluating wood must focus on identification of those characteristics that define its performance (such as density, knots, moisture content, etc.). In existing buildings being considered for solar retrofit, questions of performance of wood components must address: (1) evidence of degradation of these products by the environment (e.g., moisture, temperature, chemicals, etc.); (2) presence of properly specified product grade and size; and (3) proper joining of components. Assessment techniques for wood include field inspection procedures discussed in the remainder of this section and in table 6, and the more detailed assessment procedures listed in appendix D.2.

3.4.2 Problems Affecting Wood Components

Common problems affecting the strength of structural timber are as follows:

A. Moisture Degradation [1, 2, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22]

In relatively dry climates with moderate temperatures, where wood is protected from deteriorating influences, the mechanical properties of wood show little change even after several centuries of aging. However, the strength of wood subjected to high moisture conditions can be adversely affected. The physical action of take-up or release of moisture causes swelling or shrinkage which can cause warpage, checking, and/or splitting, all of which have an effect on the strength of wood.

Moisture in sufficient quantity to damage wood can arise from: (a) external sources such as ground moisture and wetting from rain, and (b) internal sources such as high relative humidity, or moisture related to building occupancy (e.g., leaking pipes). Decay due to excessive moisture can result in various types of rot, mold and fungi growth.

B. Temperature Effects [1, 11, 12, 13, 14, 15, 17, 20]

The strength of wood increases as the temperature is cooled below 20°C (68°F), and it decreases as the temperature is raised above this point. This temperature effect is immediate and is dependent on the moisture content of the wood. When wood is exposed for prolonged periods to high levels of moisture and heat (65°C or 150°F), thermal decay and related problems (such as fungus, insect infestation, etc.) are likely to reduce the strength of the wood.

C. Insect Damage [11, 13, 14, 15, 18, 20, 23, 24, 25, 26, 27]

This can occur in seasoned or unseasoned lumber, as well as in standing trees and logs. Generally, insect infestation is most predominant in geographical areas that are conducive to high moisture and warm temperature and, particularly, when there is a wood/soil contact condition present. There is no positive method for determining the amount of reduction in strength attributable to insect damage just from the appearance of the wood. When structural

strength is a concern, the safest procedure is to replace all pieces of wood containing evidence of insect infestation.

The three major types of insects which attack wood are termites, power-post beetles, and carpenter ants. The most common areas where termites are found are in: (1) warm, moist, soil that has an abundance of cellulose derivatives, (2) poorly ventilated spaces below the first floor of a building, (3) areas of wood in contact with the soil, and (4) soil near walls of heated basements. Power-post beetles are found in humid locations, especially near the ground. Their presence can most readily be determined in wood by irregular burrows made by the larvae, while the surface shows only small diameter holes. The presence of carpenter ants is manifested by piles of chewed wood resembling coarse sawdust outside the wood and by the hollow, irregular, clean chambers made in wood.

D. Chemical Degradation [1, 11, 12, 13, 14, 15, 18]

Wood is generally resistant to mild acids and solutions of acidic salts. Some chemical solutions, however, may react with the chemical constituents of wood and cause a reversible swelling or irreversible changes in the wood to occur. One of the most common evidences that chemical degradation is taking place in wood is surface discoloration which occurs as it is exposed to the atmosphere and ultraviolet radiation. The chief means of combating chemically degrading forces is to coat the wood with preservatives, water repellants, or paint coatings.

3.4.3 Preliminary Evaluation of Wood Components

The on-site investigation conducted at the preliminary evaluation stage (figure 1) will provide information concerning the size, strength, grade, and extent of surface decay of structural timber in existing buildings. A useful aid for evaluating structural timber is the grade mark stamped on it at the mill. Because grade marks usually can be related to a recommended design value (by reference to the National Design Specification for Wood Construction, or other relevant documents), it is helpful in determining the quality and strength properties of the existing timber structure of a building if they can be discerned. If the grade marks are not discernible, it may be necessary to engage an evaluator who is experienced in identifying and grading wood products to make the evaluation of the quality and strength properties of the in-situ structural timber.

Table 6 summarizes the on-site inspection techniques for wood.

3.4.3.1 Guidelines for Visual Inspection

Visual inspection can provide information on the extent of decay in wood components. As discussed in section 3.4.1 decay can be the result of fungus or insect infestation, extreme weathering, or moisture accumulation. Characteristics of decay to be noted in different types of structural components are given in the following table:

Component	Characteristics of Decay
Siding	Abnormal coloring (deeper than normal brown color); cubical checking (indicates an advanced stage of decay); bleaching (with or without the presence of fine black lines); softening (especially where siding ends butt against trim or each other).
Foundations	Fanlike growth of fungi (located between subfloor and finish floor, and between joists and subfloor).
Roofs	Cubical checking, warping, softening, shredding, breakage (location of all these deficiencies may be on the underside of roof sheathing).
Porches	Same as siding (check especially concavely worn areas that may trap water).
Windows and Doors	Brown or black discoloration near joints. Stain on sash (from condensation). Softening and mold growth (from accumulation of condensate).

Visual inspection will yield a good overall idea of the in-situ condition of wood and is the preliminary step in further evaluation of a member's strength properties. Any additional inspections should include an assessment of the wood member's internal stability. When conducting a visual inspection, keep in mind that this is a subjective test, and the accuracy of the results will depend completely on the skill of the inspector.

During the visual inspection, the following significant structural aspects should be checked or considered:

A. Inspect carefully for a sag in the wood roof structure. Especially, attempt to examine the rafters, purlins, collar beams, and ridge boards. Where applicable, check the condition of the roof boards from inside the building.

B. All existing dead and live loads on the wood roof structure should be summed to determine the accumulative existing loads and to determine whether the additional loads imposed by the retrofit solar components can be supported by the existing wood framing of the building. The design capacity of the affected components of the existing wood frame should be checked with the respect to snow, ice, and wind loads for the local geographical area, as well as the dead loads for the roofing materials.

C. Wherever possible, new columns or equipment supports should be placed directly over existing columns. Therefore, the interior of the building should be inspected to determine whether there are any conditions which would prevent this from being accomplished.

3.4.3.2 <u>Visual Stress Grading</u> [1]

Visual stress grading is simply an attempt to place stock lumber in broad categories of anticipated load bearing capacities. The lumber usually is rated into classifications of 40, 50, 65, and 75 percent of the strength of perfect timber. Obviously, the various grades are earmarked for varying uses according to their strength rating. The characteristics that determine a visual stress grade include size and frequency of knots, slope of grain, and wane. Visual stress grading yields an approximate, conservative estimate of a member's strength. This is because there is no allowance made for specific gravity of the wood, and only the surface is available for inspection.

The advantage of visual stress grading is that it is a fast and easy method for obtaining a general idea of in-situ timber quality. A disadvantage is that an experienced evaluator is required.

3.4.3.3 <u>Manual Probing</u> [19, 28, 29]

Prodding or probing a suspected piece of decayed wood with a sharp tool and observing the resistance to marring gives an idea of the stage of surface decay. A loss of hardness can be determined by comparison with sound wood of the same stock and species. Sound wood tends to lift out of the stock as one or two long silvers with splintery breaks when jabbed with a pointed tool. Decayed wood tends to lift out and break off squarely across the grain with little splintering and little resistance.

Manual probing will yield an accurate assessment of in-situ surface conditions, but it must be used in conjunction with another test method to determine the internal quality. The probing method is best suited to framework, siding, and fences. Penetrometers often are used to determine the quality and uniformity as well as strength properties of wood.

3.4.4 Wood Problems and Potential Impact on Solar Retrofit

A checklist (table 7) can be used to assist in determining what problems exist in the wood system of an existing building and to make a preliminary determination of the impact that the problem may have on the solar retrofit.

TABLE 6. TEST METHODS FOR WOOD

Visual/Optical	Property or Parameters	Capability	Advantages	Limitations
Visual Inspection	Extent of Decay. Species.	Visual inspection to search characteristics of decay that are typical of different structural components (such as siding, roofs, etc).	A good preliminary step in structural assessment to yield an overall evaluation.	Inspection should be followed by other tests to assess internal stability.
Visual Stress Grading	Strength and Grade	Examination of such qualities as size and frequency of knots, grain slope, and wane which lead to a stress reduction factor (compared to stress value of clear wood).	It is well suited for grading inspection. Provides a measure of structural adequacy related to conventional practices under accepted ASTM/ALS grading practices.	Limited to accessibility. May be impractical if grade mark or wood is covered with paint
Manual Probing	Extent of Decay	Pulling out of surface splinters of decayed wood and comparing with splintering and breaking characteristics of sound wood.	A good detection method for surface decay. It is fast and easy, and decay characteristics are easy to identify (if they are in an advanced stage of development).	Inspection should be used in conjunction with another test method to assess internal quality. In existing buildings, not all surfaces may be accessible. Cannot measure decay unless it proceeds inwards from the surface.

TABLE 7. PRELIMINARY ASSESSMENT CHECKLIST (WOOD)

Problems	Does Problem Exists Yes No	Possible Causes to be Considered	Impact on Solar Retrofit
1. Moisture Problems:			
A. Shrinkage		Use of unseasoned lumber.	Very little effect - usually the reduction in cross-sectional area is compensated by a resulting increase in most of the strength properties. Loosened connections should be tightened to restore structural integrity of the joints.
B. Shrinkage accompanied by warpage, checking, and/or splitting.		Use of unseasoned wood.	Structural integrity might have to be restored before loading structure with solar equipment. Strength probably has been reduced.
C. Swelling accompanied by warpage, checking, etc.		Moisture absorbed from ground, rain, or high relative humidity (occupational moisture, condensation, etc.).	Structural integrity probably has been reduced and should be restored before adding solar equipment loads.
D. Decay			
D.1 Brown rot (usually in soft woods).		Moisture (consistently higher than 19 percent) and oxygen - in a temperature range of 10 - 32°C (50-90°F).	Wood has experienced a loss of cellulose with accompanying reduction in strength. Solar equipment should not be added to a structure affected by brown rot.
D.2 White rot (usually found in hardwoods).		Moisture and oxygen (see D.1 above).	Wood has experienced degradation of both lignin and cellulose with accompanying reduction in strength. Solar equipment should not be added to a structure which is affected by white rot.
D.3 Soft Rot		Moisture and oxygen (see D.1 above).	Damage usually is only a few millimeters deep. Check for sufficient remaining effective cross-sectional area of the wood member before loading with solar equipment, and eliminate source of moisture damage.

TABLE 7. PRELIMINARY ASSESSMENT CHECKLIST (WOOD) - (CONTINUED)

Problems	Does Problem Exist? Yes	No	Possible Causes to be Considered	Impact on Solar Retrofit
D.4 Water conducting rot (sometimes called dry rot).			Fungi conducts ground water into an otherwise dry wood.	Usually is devastating - severe structural damage. Do not load solar equipment on affected members.
D.5 Molding and staining fungi			Moisture and oxygen (see D.1).	Usually have no effect on structural integrity. Cleaning for aesthetic reasons may be desirable before retrofitting with solar equipment.
2. Temperature Problems:				
A. Exposure to prolonged heating between 20°C -66°C (68°F - 150°F).			High ambient temperature.	Strength of wood decreases. Although the change is reversible, if high ambient temperature is expected to continue, effective strength must be estimated carefully taking into account the strength reduction.
B. Exposure to prolonged heating above 65.5°C (150°F).			High ambient temperature.	Usually, there is a permanent loss of strength. Before adding solar equipment loads, estimate reduced strength of structure.
3. Marine Borer and Insect Infestation:				
A. Small holes in surface of wood.			Mollusks	Extremely damaging to untreated wood. Do not load with solar equipment.
B. Shallow galleries near surface of wood (honeycombing)			Crustacean borers	Wood is vulnerable to erosion and other problems. Eliminate cause of problem and estimate reduced effective area of wood before adding solar equipment loads.

TABLE 7. PRELIMINARY ASSESSMENT CHECKLIST (WOOD) - (CONTINUED)

Problems	Does Problem Exist? Yes	No	Possible Causes to be Considered	Impact on Solar Retrofit
C. Signs of discarded termite wings; hollow wood beneath surface; galleries or earthern shelter tubes on foundation walls or along plumbing; fecal pellets on outside of wood; entrance holes that are sealed with a brownish-black paper-thin secretion.			Termites	Structural integrity can be destroyed completely. Do not load solar equipment on wood members affected in this manner.
D. Irregular burrows inside wood with small holes (approx. 3.2mm dia.) in the surface.			Powder-post beetles	Structural integrity may be destroyed completely. Do not load solar equipment on members affected in this manner.
E. Piles of chewed wood (resembling coarse saw-dust), and hollow, irregular, clean chambers cut across the grain. Usually in softwoods.			Carpenter ants	Carpenter ants do not eat the wood-they just nest in it, so damage may be limited. Some structural strength reduction may be expected and should be assessed before loading solar equipment on affected member.
4. Chemical Degradation:				
Surface discoloration, thin gray layer (often accompanied by swelling).			Alkaline solutions are more destructive than acidic solutions, but either could cause damage. Exposure to atmosphere and ultra-violet radiation is common cause.	Cellulose fibers are degraded with resulting loss of strength. Area affected usually is confined to surface (down to 6.3mm). Effective cross-sectional area and reduced strength should be estimated before loading with solar equipment.
5. Organic Degradation:				
A. Cross grain (spiral, diagonal, wavy, dipped, interlocked, and curly grain).			Irregular growth of tree, or improper sawing of lumber.	It can seriously degrade the mechanical properties or machining characteristics of the wood. The reduced strength value of the wood should be calculated before loading it with solar equipment.

TABLE 7. PRELIMINARY ASSESSMENT CHECKLIST (WOOD) - (CONTINUED)

Problems	Does Problem Exist? Yes	No	Possible Causes to be Considered	Impact on Solar Retrofit
B. Knots			Natural cause (the area of the base of a branch of the tree).	Knots decrease the mechanical properties of wood in tension. Usually compression strength is not affected adversely. Reduced strength value should be determined before loading affected member with solar equipment.
C. Pitch Pockets (openings which run parallel to the annual rings).			Lack of bond between annual growth layers.	The effect on the mechanical properties of the wood may be severe if found in large numbers.
D. Reaction Wood (abnormally dense wood tissue).			Formed by the tree as a natural response to correct for leaning boles and crooked limbs.	Because of its unsual denseness, it often is stronger than normal wood of the same species. Because it experiences greater than normal longitudinal shrinkage due to loss of moisture, it can cause warping when present with normal wood. Usually has no structural effect.
E. Compression Failures (light colored lines or zones on the surface of the wood). Often they are detected by evidence of fiber breakage on end grain.			Formed by the crumpling or buckling of wood cells by rough handling of logs or lumber.	Tensile strength and shock resistance can be lowered. Strength of affected members should be determined before loading with solar equipment.
6. Fire Damage (Char)			Fire	Effective cross-sectional area and strength are reduced. Remaining net section of uncharred wood should be determined to estimate remaining strength before loading affected members with solar equipment.

3.5 MASONRY SYSTEMS

3.5.1 General

Since many of the existing buildings being considered for solar retrofit are constructed of masonry, it becomes important to know how to evaluate the condition of the masonry and to determine whether it is capable of supporting the loads expected to be imposed by the retrofit solar equipment. This is especially true of load bearing masonry assemblages which are expected to support: (1) heavy loads (such as water storage tanks, rock beds, absorption chillers, etc.), (2) dynamic or vibrational loads from rotating or reciprocating equipment, or (3) changes in type of live loads caused by the rehabilitation of the building (e.g., change in occupancy). As used in this discussion, masonry is broadly defined to include products such as hollow and solid masonry units, gypsum masonry, glass masonry, natural building stone, adobe block, clay building bricks, concrete block, and structural clay tile.

3.5.2 Preliminary Evaluation of Masonry

As shown in table 8, there are several field inspection techniques discussed in this section which can provide useful information on surface properties of masonry (flaws, discoloration, cracks, etc.), deficiencies in mortar joints, differential structural movement, dimensional characteristics, and location and uniformity of inner cell grout. More detailed assessment procedures are summarized in appendix D.3 for determining masonry properties (e.g., compressive or diagonal tensile strength, location of steel reinforcement, flexural bond strength, moisture content, modulus of elasticity, chemical resistance).

3.5.2.1 Visual/Optical Inspection [30, 31, 32, 33]

Visual/optical inspection methods usually are the least expensive and most commonly used means of detecting surface flaws in masonry construction. Defects (such as surface cracks in bed mortar or at bonded interfaces, nonbonds, missing or defective mortar, erosion, corrosion, misalignment, etc.) most often can be detected with the naked eye. With the use of optical magnifiers, very small surface defects (as small as only a few microns wide) can be detected.

Visual measurement can be used to determine the size and/or warpage of masonry construction. Either a steel scale, a gauge or caliper, or a steel measuring wedge can be used to determine the size and warpage of the masonry units.

Using binoculars, focus on areas of the roof that are particularly subject to leaks (e.g., joints between converging slopes and around chimneys, exposed flashing, gutters, downspouts, etc.). Especially look for areas where mortar appears to lighten in color (an indication of patching), or where mortar appears to be crumbling. Also, scan the exterior wall of the building for any obvious signs of bulging in the brick (especially near the bottom of the wall or near openings. These bulges usually are an indication that the mortar

has failed or (in the case of brick veneer) that the ties between the veneer and the structure of the building have deteriorated.

Inspect visually for horizontal cracks in the middle of a basement wall. If the cracks are accompanied by obvious inward bulging, this indicates excessive pressure being exerted by the soil outside the wall which could be caused by excessive ground-water pressure or by compaction from adjacent new construction work. Vertical cracks located in a corner of the basement that widen to 6.35 mm (1/4 in) or more at the top often are caused by a settling footing beneath the foundation. Any of these types of cracks could jeopardize the structural integrity of the entire basement wall.

During the visual/optical inspection, the following significant structural aspects should be checked or considered:

A. Check for soft and crumbling mortar in masonry foundation walls. This condition could be serious if it is associated with any signs of sag in the structure.

B. Masonry foundation cracks usually are diagonal, starting from the top, the bottom, or the end of the wall. If the cracks do not extend to at least one edge of the wall, they probably are not caused by foundation problems. It is important to determine the cause of these problems and remedy the situation because the addition of retrofit solar equipment loads on the building could aggravate the problem further.

C. When new heavy loads are expected to be added to the existing masonry foundation, it will be necessary to check it for structural adequacy. If details of the masonry foundation design and the soil bearing value cannot be determined from existing drawings and reports of subsurface soil investigations, it may be necessary to: 1) excavate adjacent to an outside wall to determine the type of existing foundation, and 2) conduct a subsurface soil investigation (soil borings). Results from the subsurface soil investigation can be used to support the need for new foundations under heavy loads or to prove the adequacy of existing foundations.

D. All existing dead and live loads on the roof structure and affected masonry supporting walls should be summed to determine the accumulative existing loads and to determine whether the additional loads imposed by the retrofit solar component can be supported by the existing masonry structure. The design capacity of the affected components of the masonry structure should be checked with respect to expected snow, ice, and wind loads for the local geographical area, as well as the dead loads of the roofing materials.

E. Whenever possible, new columns or equipment supports should be placed directly over existing columns. Therefore, the interior of the building should be inspected to determine whether there are any conditions which would prevent this from being accomplished.

3.5.2.2 Hammer Test [34]

The hammer test is an inexpensive and unsophisticated method of estimating the condition of a masonry unit or assemblage by the sound that it produces when tapped lightly with a hammer. Although the results are questioned by many evaluators, some very experienced people (who have a keen sense of hearing and touch) claim to have the ability to determine the structural soundness of masonry units and mortar and to determine whether the cells of the units are filled, by the use of this test method. Experience and credibility on the part of the evaluator is required, however, before any degree of reliance should be placed on the interpretation of the results. Even then, it may be desirable to use test borings to confirm the findings.

3.5.2.3 Probing [34]

The location and uniformity of the inner cell grout and wall thickness of a masonry unit or assemblage can be determined by penetrating the area of investigation with a small masonry drill bit and probing the hole with a stiff wire. Small holes may be patched easily leaving only minor surface damage.

Probe the mortar joints with an awl or ice pick to determine whether it is soft and sandy or falls out easily.

3.5.2.4 Ink Test [35]

Using permanent blue-black fountain pen ink, it is possible to estimate the imperviousness and opacity of ceramic glazed facing tile, brick, and solid masonry units. To test for imperviousness, the ink is applied to the glazed surface of 5 dry specimens for 5 minutes. The surface then is washed and examined for stain of the finish. Opacity may be determined by applying the ink along a 50 mm (2 in) length of the edge of the finished surface. After 5 minutes, the finish is examined visually for opacity. ASTM C 126 describes these two tests in greater detail.

3.5.3 Problems Affecting Masonry Components

Some of the most common problems affecting the strength of masonry units or assemblages used in building construction are as follows:

A. Cracking [31, 33]

Cracking usually is not an indication that a building is becoming structurally unsafe. It is normal therefore to find some cracking in the masonry of almost every building. In fact, it is very rare for a building to collapse soon after the appearance of even large cracks.

Cracks usually result from forces being applied to the building which are greater than the loads for which the building was designed. These loads may include:

1. Overloading due to excessive external forces such as snow, wind, etc.; or internal forces such as heavy equipment loads, change in occupancy loads, etc.

2. Forces induced by temperature changes causing differential movement of the building materials.

3. Ground movement (subsidence, slippage, shrinkage, or quakes) causing part of the building to become displaced from the rest of the building.

4. Changes in moisture content of the masonry materials. This can lead to chemical reactions (such as corrosion of the reinforcement or sulphate attack on Portland cement) or volume changes (swelling or shrinkage).

5. Atmospheric pollution such as carbon dioxide attack which causes carbonation of Portland cement and subsequent shrinkage.

B. Spalling

As used in this report, spalling is a chipping or scaling of the surface of masonry similar to the same effect in concrete. Often, it is caused by vibrational, impact, or shock loads.

C. Deterioration

Deterioration is described in this report as a break-down or disintegration of the material properties of masonry. A typical example is the softening (or crumbling away) of the matrix in the brick or mortar due to chemical attack.

D. Moisture

Moisture can be a problem in itself (causing swelling or shrinkage of the masonry), or it can be the cause of other problems previously mentioned (cracking, spalling, or deterioration).

All of these problems can have a serious detrimental effect on the structural integrity of the masonry units or assemblages and should be investigated thoroughly to determine whether they significantly limit the addition of the proposed solar retrofit equipment.

3.5.4 Masonry Problems and Potential Impact on Solar Retrofit

A checklist (table 9) can be used to assist in determining what problems exist in a masonry structure and to make a preliminary determination of the impact that the problem may have on the solar retrofit. If it is determined that a more complete understanding of the nature or cause of the problem is necessary, further reference is given in the table to a more detailed description in appendix D.3.

TABLE 8. TEST METHODS FOR MASONRY

Material	Test Parameter	Test Method	Comments	Reference
Masonry Units	Size	Visual measurement	Use either a steel metric (or 1 ft.) scale, or s gauge or caliper with a scale ranging from 25 to 300mm (1 to 12 inches) and having parallel jaws. Of no value in determining strength or durability.	ASTM C 67
	Wsrpage	Visual measurement using a scale or measuring wedge.	Use either a steel metric or 1 ft scale or a steel measuring wedge. The wedge shall be numbered to show the thickness of the units. Of no value in determining strength or durability.	ASTM C 67
Masonry Assemblages (Units and Mortar)	Structural soundness of units, bond with mortar, snd whether cells are filled.	<u>Hammer Test</u> Lightly tap the masonry unit with a hammer. Listen to resonant sound. A very experienced evaluator might be able to determine the condition by the sound.	This test requires an experienced person with a good sense of hearing and a delicate touch. It is an unsophisticated test with questionable results. Test cores may be needed to validate findings.	Snell, L.M., "Nondestructive Testing Techniques to Evaluste Existing Masonry Construction," August, 1978.
	Location and Uniformity of the inner cell grout and wall thickness.	<u>Probe Holes</u> Penetrate the area of investigation with a small masonry bit and probe the hole with a stiff wire.	Small holes may be patched easily. Surface damage is only minor.	Snell, L.M. "Nondestructive Testing Techniques to Evaluate Existing Masonry Construction," August, 1978.
Ceramic Glazed Facing Tile and Brick	Imperviousness	Permanent blue-black fountain pen ink is applied to the glazed surface of 5 dry specimens for 5 minutes. The surface is washed and examined for stain of the finish.	Of no value in determining strength or durability.	ASTM C 126

TABLE 9. PRELIMINARY ASSESSMENT CHECKLIST (MASONRY)

Problems	Does Problem Exist? Yes	No	Possible Causes to be Considered	Impact on Solar Retrofit
1. Cracks				
A. Vertical cracks-usually straight. Widest at top of building and taper to hair-line at foundation or at the top of an opening in ground floor wall.			Swelling of clay soil under foundation.	If foundation is too shallow to be below the level of clay, condition is likely to be at its worst. Cracks may require only cosmetic patching unless structural components have been affected by the movement. Structural assessment is advisable before adding load of solar equipment to the foundation or affected component.
B. Vertical cracks near the corner of the building. Usually extend from ground level dampproofing course up to 3m.			Moisture expansion in bricks and/or thermal movement.	Structural assessment should be made to determine if solar equipment can be added without detrimentally affecting the structural integrity of the wall.
C. Vertical cracks near center of a cavity wall panel. Usually extend vertically up to 3m through the bricks in alternate courses. Taper to hair-line at top. Usually accompanied by bulging of external wythe.			Expanding clay brickwork. Movement is constrained by columns at ends of affected wall panel.	None if solar equipment loads bear on columns. If wall is to be used as load bearing, structural assessment should be made to determine capability to take new loads without detrimental effects.
D. Vertical or diagonal cracks in calcium silicate bricks or concrete blocks. Usually between windows, window and roof, window and dampproofing course.			Shrinkage during curing stage or aging.	None if solar equipment loads bear on columns. If wall is to be used as load bearing, structural assessment should be made to determine capability to take new loads without detrimental effects.
E. Other vertical cracks in masonry walls.			Uneven settling of foundation from: 1) poor design, 2) footings above frost line, 3) creeping or weak soil.	None if solar equipment loads bear on columns. If wall is to be used as load bearing, structural assessment should be made to determine capability to take new loads without detrimental effects.
F. Diagonal cracks across corner (affecting two adjacent walls). Widest at corner; becomes narrower as it progresses diagonally downward.			Subsidence of soil and foundation wall below the cracked area from drying and shrinkage of the soil.	None if solar equipment loads bear on columns. If wall is to be used as load bearing, structural assessment should be made to determine capability to take ne loads without detrimental effects.

TABLE 9. PRELIMINARY ASSESSMENT CHECKLIST (MASONRY) - (CONTINUED)

Problems	Does Problem Exist? Yes	No	Possible Causes to be Considered	Impact on Solar Retrofit
G. Diagonal cracks at various places in the building. Widest at foundation, reducing toward top of building.			Heaving of foundation from swelling clay sub-soil. If the masonry units are calcium silicate or concrete, cracks may be caused by shrinkage of units.	None if solar equipment loads bear on columns. If wall is to be used as load bearing, structural assessment should be made to determine capability to take new loads without detrimental effects.
H. Diagonal cracks in clay brickwork. From damp-proofing course near the ground to an opening in the wall.			Moisture expansion of bricks. Sometimes accentuated by thermal expansion.	None if solar equipment loads bear on columns. If wall is to be used as load bearing, structural assessment should be made to determine capability to take new loads without detrimental effects.
I. Horizontal cracks in the mortar joints of clay bricks. Often associated with over-sailing of bricks. In cavity walls the outer wythe may expand. Most common at parapets, garden walls, chimneys, and under window sills.			Chemical action on the Portland cement or semi-hydraulic lime in the mortar by soluble sulphate salts in bricks.	None if solar equipment loads bear on columns. If wall is to be used as load bearing, structural assessment should be made to determine capability to take new loads without detrimental effects.
J. Horizontal cracks at third or fourth - course intervals.			Corrosion and expansion of galvanized iron or steel wall ties (where embedded in black ash mortar).	None if solar equipment loads bear on columns. If wall is to be used as load bearing, structural assessment should be made to determine capability to take new loads without detrimental effects.
K. Horizontal cracks at eaves level of pitched roofs (often associated with outward movement of top few courses).			Spreading of the structural components of the roof from poor design, a change in roofing materials, or weakened roof members.	The roof structure should be thoroughly checked for load capacity before adding loads of roof mounted solar equipment.
L. Horizontal cracks at top or bottom of window openings or immediately below a concrete roof slab.			Expansion of the flat roof from being heated by the sum. Joint between roof and walls is too rigid.	The roof structure should be thoroughly checked for load capacity before adding loads of roof mounted solar equipment.

TABLE 9. PRELIMINARY ASSESSMENT CHECKLIST (MASONRY) - (CONTINUED)

Problems	Does Problem Exist? Yes No	Possible Causes to be Considered	Impact on Solar Retrofit
M. Horizontal cracks at courses of masonry near floor slabs (often accompanied by bowing of brickwork or out-of-plumb cladding panels.		Shrinkage of cast-in-place concrete frame members compresses panels between horizontal or vertical frame members.	Additional loads of solar equipment on frame of building could worsen the problems.
N. Cracks which are variable in direction and width.		Movement of ground under foundation, or chemical attack on the mortar or the Portland cement in the foundation by sulfates in the soil or brick.	Additional solar equipment loads could worsen the foundation movement and resulting cracks. Soil may need strengthening, or existing loads on structure may have to be reduced before adding solar equipment loads.
O. Cracking of parapets.		Movement of parapets at roof level dampproofing course due to 1) moisture expansion of brick, 2) freeze-thaw action, 3) sulfate attack on the mortar, 4) thermal expansion of the bricks, or 5) thermal movement of the roof (if it is a flat roof).	Additional solar equipment loads could worsen the foundation movement and resulting cracks. Soil may need strengthening, or existing loads on structure may have to be reduced before adding solar equipment loads.
2. Spalling			
A. Spalling of bricks at line of floor slabs or other places of support. Usually at dampproofing course or where brickwork projects in front of edge of the supports.		Brickwork is too rigid and too close to concrete framework of the building to accommodate movement of the framework from moisture or thermal expansion.	Additional solar equipment loads could worsen the foundation movement and resulting cracks. Soil may need strengthening, or existing loads on structure may have to be reduced before adding solar equipment loads.
B. See, also, the discussion of spalling in table 5.			
3. Deterioration			
A. Surface deterioration of clay brickwork.		Freeze-thaw or salt action (crystallized calcium, magnesium, sodium, and potassium sulphates).	None-unless masonry is used in bearing walls supporting solar equipment, and then only if the surface deterioration is so severe that it reduces the effective area of the units. Porosity of masonry units may need sealing.

TABLE 9. PRELIMINARY ASSESSMENT CHECKLIST (MASONRY) - (CONTINUED)

Problems	Does Problem Exist? Yes No	Possible Causes to be Considered	Impact on Solar Retrofit
B. Lime blow in bricks.		Fossils of chalk, limestone, or calcite.	None-unless masonry is used in bearing walls supporting solar equipment, and then only if the surface deterioration is so severe that it reduces the effective area of the units.
C. Pitting of stone walls in contact with pavements.		Efflorescent salts, from lack of dampproofing course to prevent vertical passage of water from pavement.	None-unless masonry is used in bearing walls supporting solar equipment, and then only if the surface deterioration is so severe that it reduces the effective area of the units.
D. Surface erosion of natural stone.		Atmospheric pollution, freeze-thaw action, or crystallization of soluble salts.	None-unless stonework is used in bearing walls supporting solar equipment, and then only if there is deterioration or cracking which would affect the structural strength. Excessive porosity of stonework may need sealing.
E. See, also, the discussion of deterioration in table 5.			
4. <u>Moisture</u>.			
A. Dampness on internal walls located below parapets of flat roofs.		Damaged flashing at intersection of the flat roof and the parapet. Lack of dampproofing course at base of parapet. Improper design of dampproofing course at base of parapet.	None-unless masonry is used in bearing walls supporting solar equipment and then only if there is deterioration or cracking which can affect the structural strength.
B. Dampness and a film of salts on interior face of external masonry walls at or near the ground level.		Capillary transmission of water from damp soil. Often results from inadequate dampproofing in the wall.	None-unless masonry is used in bearing walls supporting solar equipment and then only if there is deterioration or cracking which can affect the structural strength.
C. Leakage through cracks or voids of masonry basement walls during a rain or soon afterwards.		Rain water leakage or capillary action of moisture from the damp soil.	None-unless masonry is used in bearing walls supported solar equipment and then only if there is deterioration or cracking which can affect the structural strength.

TABLE 9. PRELIMINARY ASSESSMENT CHECKLIST (MASONRY) - (CONTINUED)

Problems	Does Problem Exist? Yes	No	Possible Causes to be Considered	Impact on Solar Retrofit
D. Dampness on masonry cavity walls or solid walls during a rain or soon afterwards. Especially over windows and doors and wherever wall ties and cavity gutters are used.			1) Bridging materials in the cavity causing transfer of moisture between wythes. 2) Cavity gutters have been split or punctured. 3) Wall ties are sloped inward or drip edge not centered in cavity. 4) Weep holes not provided in horizontal joint just above the cavity gutter (or clogged weep holes).	None-unless masonry is used in bearing walls supporting solar equipment and then only if there is deterioration or cracking which affect the structural strength.
E. Bowing or over-sailing of brickwork at any damp-proofing course. Often accompanied by a vertical crack at or near the point of maximum bow.			Moisture expansion of bricks may be exaggerated by freeze-thaw damage or sulphate attack.	None-unless masonry is used in bearing walls supporting solar equipment and then only if there is deterioration or cracking which can affect the structural strength.
F. Dampness on internal masonry walls. Usually at top of walls and columns in buildings where the upper elevation is set back so internal wall in question becomes an external one.			Defective waterproofing at base of external portion of the wall in question (where it joins the roof). Slope of roof feeding water onto piers of columns which might subdivide the wall.	Roof mounted solar equipment could seriously worsen the problem, especially if loads cause worsening of improper roof slopes. Special attention will have to be given to mounting details and location and to waterproofing details.
G. Dampness on the inner surface of masonry curtain walls soon after a rain.			Leaks in exterior cladding. Defective glazing beads, sealant, etc.	None-unless masonry is used in bearing walls supporting solar equipment and then only if there is deterioration or cracking which can affect the structural strength.
H. Dampness and discoloration of natural stone external walls in contact with pavements.			Efflorescent salts, from lack of dampproofing course to prevent vertical passage of water from pavement.	None-unless masonry is used in bearing walls supporting solar equipment, and then only if there is deterioration or cracking which can affect the structural strength.

TABLE 9. PRELIMINARY ASSESSMENT CHECKLIST (MASONRY) - (CONTINUED)

Problems	Does Problem Exist? Yes	No	Possible Causes to be Considered	Impact on Solar Retrofit
I. Dampness on masonry chimney flues serving appliances. Usually on the ceiling (at or near the eaves level), but sometimes on the external brickwork.			Extremely damp or foggy weather.	None
J. Dampness from occupational moisture.			Breathing; laundering; bathing; cooking; leaking pipes, tanks, and cisterns; excessive cleaning water; plant life; humidifiers or steam radiators; combustion of oil, gas, or coal fuels; spillage of industrial liquids.	In the case of spillage of industrial liquids, there is the problem of the possibility of contamination from chemicals which might be harmful to the masonry materials.
K. Condensation			Adjacent air conditioned rooms, inadequate ventilation, inadequately insulted cold pipes and air ducts, steam radiators, devices burning fuel containing hydrogen, improperly insulated walls or floors, occupant induced moisture sources, etc.	None-unless masonry is used in bearing walls supporting solar equipment, and then only if there is deterioration or cracking which can affect the structural strength.

3.6 METAL SYSTEMS

3.6.1 General [36, 37]

Flaws in the steel structure of a building are not as subject to fatigue (from cyclic vibrations, etc.) as flaws in other structures (such as bridges). Therefore, it may not be critical to evaluate them in relation to their ability to support new solar equipment loads.

If, however, it has been determined that a structural component (weldment, splice plate, etc.) is suspected of degrading the structural integrity of the building, nondestructive evaluation methods can be extremely useful. As a result of improved techniques, these test methods are becoming increasingly more important for evaluating the metal structure of buildings. It is important, to evaluate other flaws than cracking. Corrosion, voids, pits, fabrication discontinuities, and porosity can affect structural integrity and the ability of the existing structural system to support new solar retrofit equipment.

Most nondestructive test methods offer more than a superficial examination of the surface conditions of metals. Such tests may reveal properties, quality, and dimensions of both the surface and internal regions of many metal test specimens.

Although most of the test methods for metals mentioned in this report will be used primarily for structural steel, many are applicable to other types of ornamental and structural metals (e.g., cast-iron, aluminum, etc.) as indicated in the summary tables in this section and in section D.4 (detailed evaluation methods).

Usually, the most important factors of structural steel to determine are: 1) dimension, 2) type of steel, and 3) the age of the steel in order to determine its strength.

Factors to consider in selecting an appropriate nondestructive test of metals are:

1) What is the material to be tested?

    a. Is it magnetic or nonmagnetic?
    b. Is it electrically conductive?
    c. Does the metal have a nonconductive or nonmagnetic coating?

An easy method to determine whether a structural member is made of wrought iron or steel is to apply dilute nitric acid to a clear section. If the member is made of steel, the test section will turn black; whereas, the wrought iron will not be affected.

2) How was the metal fabricated (cast, wrought, powder metallurgy, welded, soldered, etc.)?

3) What is the geometry of the component (dimensions, shape, surface irregularities etc.)?

4) What types of defects are possible or expected in this type of metal?

5) What degree of sensitivity and resolution is required from the test equipment?

6) What are the equipment, testing, and materials costs?

7) How accessible is the component (e.g., behind a wall; concealed by ductwork, etc.)?

There are several on-site testing methods which can be used during the preliminary evaluation stage (figure 1). These can provide useful information concerning surface defects (cracks, voids, fabricating discontinuities, pits, poor bonding, porosity, laps, seams, and other irregularities). Some of the most commonly used are included in the following table. Other methods which are part of the detailed evaluation stage, are summarized in appendix D.4 and can be used to assist in determining additional properties.

3.6.2 Preliminary Evaluation of Metal Systems

Several preliminary evaluation procedures exist to determine the surface properties of metal structural components. It should be realized, however, that these test methods have limited application in that they do not provide information on the internal physical condition of the metal structural member. In order to obtain an estimate of the internal condition and the strength of the metal, the more complex test methods described in appendix D.4 will have to be used.

As with the other structural materials, the most important areas to investigate are the areas of high shear and low moment. It is at these stress points where the defects and structural failures are most likely to occur. Therefore, the investigator should concentrate on inspection of these particular areas of concern.

3.6.2.1 Visual Inspection

Visual inspection is the least expensive and most commonly used means of detecting surface flaws in metal construction. Surface flaws (such as cracks, voids, fabricating discontinuities, pits, poor bonding, porosity, laps, seams, etc.) usually can be detected using simple visual inspection techniques.

During the visual inspection, certain instruments (such as borescopes, fiber optical equipment, panoramic cameras, etc.) can be used to examine areas of the metal which are inaccessible to the naked eye. Simple magnifiers can be used to detect flaws which are too small to be seen by the naked eye. During this inspection, the following significant structural aspects should be checked or considered:

A. If the existing roof is composed of a steel deck on steel joists, and new heavy concentrated dead loads are to be imposed on the deck by solar equipment, the joists must be designed for twice the static operating weight of the equipment. Also, there must be enough room to reinforce the top chords of the joists for any new concentrated loads which may be applied between panel points. Since any new concentrated loads which must be applied to the bottom chords will have to occur at panel points, access to these points is essential. Existing joists should be checked to be sure they can support newly imposed loads wthout exceeding a maximum deflection of 1/360 times the span.

B. Wherever possible, new columns or equipment supports should be placed directly over existing columns. Therefore, the interior of the building should be inspected to determine whether there are any conditions which would prevent this from being accomplished.

C. All existing dead and live loads on the metal roof structure should be summed to determine the accumulative existing loads and to determine whether the additional loads imposed by the retrofit solar components can be supported by the existing metal structure. The design capacity of the affected components of the metal structure should be checked with respect to expected snow, ice, and wind loads for the local geographical area, as well as the dead loads of the roofing materials.

3.6.3 Table No. 10 has been developed to assist the evaluator during the visual inspection to determine the possible causes of problems encountered and to realize the impact that they may have on the proposed solar retrofit.

TABLE 10. PRELIMINARY ASSESSMENT CHECKLIST (METALS)

Problems	Does Problem Exist? Yes	No	Possible Causes to be Considered	Impact on Solar Retrofit
Fatigue cracks in structural metals.			Cyclic loads and movements usually from thermal expansion and contraction or from vibrational loads of machinery.	Any affected structural member must be thoroughly evaluated before imposing new solar equipment loads.
Steel and aluminum structural members out-of-plumb or distorted, poorly aligned connections, inaccurately placed column bases, etc.			Erectors will correct for geometric variations (warp, camber, etc.) by distorting the members during erection.	This tendency to correct for geometric variations can cause significant residual stresses in the framework of the building. It usually is difficult to detect and requires an experienced evaluator and sophisticated NDE equipment to detect and evaluate it. Any signs of distortion in the framework should be suspect of this condition and should be evaluated before placing additional solar equipment loads on the already stressed framing members.
Erosion of metals.			Abrasion	Erosion of non-structural members (flashings, sheathings, etc.) will affect the solar retrofit only in regards to degradation of the water resistance of the building and the solar components therein. Affected structural members should be thoroughly evaluated before placing new solar equipment loads on them.
Corrosion of iron and steel (used mainly for structural framing members.)			Electrolytic action of dissimilar metals in an electrolytic solution. Hydrogen-ion activity. Presence of oxygen in solution adjacent to the metal (oxygen concentration cell). Static or cyclic stresses present in the metal. Salt present in sea water or air near the ocean. Acids. Soils. Sulphur compounds.	Particular attention should be given to evaluation of strength properties of iron or steel structural members which show signs of corrosion. Affected structural members should be evaluated and strength should be determined before loading with solar equipment.

TABLE 10. PRELIMINARY ASSESSMENT CHECKLIST (METALS) - (CONTINUED)

Problems	Does Problem Exist? Yes No	Possible Causes to be Considered	Impact on Solar Retrofit
Corrosion of wrought iron (used mainly for structural members, roofing, pipes, chains, railings, grills, balustrades, and decorative items in buildings).		Electroyltic action of dissimilar metals in an electrolytic solutions. Hydrogen-ion activity. Presence of oxygen in solution adjacent to the metal (oxygen concentration cell). Static or cyclic stresses present in the metal. Salt present in sea water or air near the ocean. Acids. Soils. Sulphur compounds.	Wrought iron usually starts to rust more easily than cast iron, although it is resistant to progressive corrosion. Sometimes, connections will fail before the members, resulting in sudden catastrophic collapse. Wrought iron may be weakened by the excessive heat of welding. A thorough evaluation should be made of any wrought iron framing before loading with solar equipment.
Corrosion of cast iron (used mainly for structural members, facades, roof ridges and decorative details, gutters, downspouts, cornices, brackets, doors, gates, shutters, railings, grills, balustrades, stairways, pipes and fittings, plumbing fixtures, and hardware).		Electrolytic action of dissimilar metals in an electrolytic solution. Hydrogen-ion activity. Presence of oxygen in solution adjacent to the metal (oxygen concentration cell). Static or cyclic stresses present in the metal. Salt present in sea water or air near the ocean. Acids. Soils. Sulphur compounds.	Cast iron is particularly susceptible to fracturing in cold weather. It has good resistance to corrosion caused by the atmosphere and by soils. Structural member and pipes showing signs of corrosion should be carefully evaluated before adding any loads from solar equipment.
Variations in shell thickness of cast iron columns.		Eccentric placement of the core during the time of casting.	Effective cross-sectional area will vary which affects the strength. Any columns with such variations should be evaluated thoroughly before placing solar equipment loads on them.
Blowholes or cinders in the shell or variations in the crystal structure of cast iron columns.		Non-uniform cooling during casting.	Defects could affect structural strength. Any columns with such defects, variations, or inclusions should be evaluated thoroughly before placing solar equipment loads on them.

TABLE 10. PRELIMINARY ASSESSMENT CHECKLIST (METALS) - (CONTINUED)

Problems	Does Problem Exist? Yes	No	Possible Causes to be Considered	Impact on Solar Retrofit
Corrosion of copper (used mainly for decorative details, flashing, gutters, leaders, cornices, pipes, hardware, anchors, screws, lighting fixtures, etc.)			Sulphur (hydrogen sulfide, sulphur dioxide, sulphuric acid), alkalis, carbon monoxide (and other gases of combustion), and ammonia.	Since copper is not used for structural members, the addition of solar equipment should have no structural impact. Pipes which exhibit signs of corrosion will have to be evaluated if they serve solar equipment.
Corrosion of aluminum (used mainly for ornamental purposes; roofing components; siding; facades; ventilators and ducts; gutters and downspouts; and, occasionally, structural members).			Alkalines, acids (hydrochloric, formic, oxalic, halogen, sulphuric, nitric, and trichloroacetic), sodium or potassium hydroxide, lime mortar, chlorides, concrete, plaster, damp wood, and lead based paints.	Any structural members showing signs of corrosion should be carefully evaluated before adding any loads from solar equipment.
Deterioration of tin, lead, brass, bronze (used mainly for roofing, flashing, gutters, downspouts, sheathing, doors, frames, trim, ornamental work, etc.).			Acids, salts, alkalines, ammonia, cyanides, etc.	Since these metals are not used for structural framework or for piping, the effect of their deterioration on solar retrofit equipment is limited only to degrading of the water resistance or the aesthetics of the building.

4. GUIDELINES FOR HEATING, VENTILATING AND AIR CONDITIONING (HVAC) SYSTEMS

This section provides methods for evaluating existing building HVAC systems being considered for solar retrofit. These methods are intended for use in a feasibility study to help determine whether the existing HVAC systems are suitable for solar retrofit. The data and information obtained will be valuable also for the final design of the proposed retrofit solar and HVAC system. This evaluation is developed in two stages: (1) preliminary information derived from reasonably unsophisticated procedures, and (2) secondary information derived from more detailed or sophisticated procedures. This section covers the preliminary evaluation only. The secondary or detailed evaluation is contained in appendix D.5.

4.1 GENERAL CONSIDERATIONS

Some solar energy systems can be retrofitted into existing buildings to supplement energy demands for space heating, space cooling, and ventilation preheating. In general, the temperature levels in solar energy systems are lower than those commonly found in fossil fuel HVAC equipment. Also temperatures tend to fluctuate as the availability of solar energy varies. Consequently, greater care is needed in evaluating existing systems and in designing a solar system for an existing building. For example, properly oriented space will be required on the roof for solar collectors. Additional (or replacement) heat exchangers, pumps and blowers will be needed also, together with appropriate heat storage equipment, piping, ducting, and controls. Unless the existing HVAC equipment is in good condition, of suitable capacity, and adapted to solar retrofit, a solar system may not be feasible.

This section does not cover the solar design, but concentrates on methods for evaluating the existing HVAC systems and equipment. The evaluation will be based on information obtained from building system records, examination of the HVAC equipment, and measurement of system performance. Forms for collecting data are included in appendix A, and were discussed in section 2.1.

4.2 PRELIMINARY ON-SITE INVESTIGATION GUIDELINES - HVAC SYSTEMS

The on-site investigation of an HVAC system consists of a general examination of the entire HVAC system as well as the individual HVAC components (air handlers, ductwork, etc.). While the emphasis should be on the HVAC components which may be affected by the solar retrofit, the entire system becomes involved where additional HVAC loads or modifications are anticipated or where load reductions occur as a result of energy conservation measures taken. The following general inspection guidelines will be useful in making the preliminary assessment.

4.2.1 Utility Bills

Energy consumption of a building can be determined from the utility payment records of the past several years. This history of energy usage will establish a base line for a life-cycle analysis. Figure 3 provides a format for recording annual energy consumption.

FIGURE 3 [7]

HISTORIC ENERGY CONSUMPTION RECORD

For Year 19__, Annual Degree-Day ____

	Electricity		Natural Gas		Fuel Oil	
	(Kw)	($)	(Therms)	($)	(Gallons)	($)
Jan						
Feb						
March						
April						
May						
June						
July						
Aug						
Sept						
Oct						
Nov						
Dec						
Total						

(Use separate sheets if different components of the HVAC system are metered separately. This helps to estimate the loads on each components).

4.2.2 Operating and Maintenance Records

Operating and maintenance records covering the HVAC equipment will provide information such as: (1) equipment repair and replacement costs, (2) number of times the equipment was out of service, (3) frequency and nature of user complaints, and (4) changes in the functional use of building space. For example, complaints from occupants may provide clues concerning inadequate ventilation or uncomfortable temperatures, which may indicate inefficient system performance or demands which have outgrown the capacity of existing equipment. Repeated repairs or frequent replacement of equipment may indicate that the existing system is not worth retrofitting. A consulting engineer can help the building facilities engineer to interprete the operating and maintenance records.

4.2.3 Visual Inspection of HVAC System

Visual inspection of the HVAC system is essential where the original construction drawings and specifications are either no longer available, or if available, the HVAC system has been significantly modified or enlarged. Such an inspection may reveal that solar retrofit should not be considered because the existing system is obsolete, inadequate for the present load, or is not economically feasible with present equipment or fuels. Moreover, an existing HVAC system which is approaching or has exceeded its expected service life is generally not a candidate for solar retrofit. It may, however, be a good candidate for solar replacement.

4.2.4 Visual Inspection of HVAC Equipment

In evaluating the HVAC equipment, it is important to obtain as much data as possible. The nameplate data for each piece of equipment, including pumps, blowers, air handlers, terminal units, compressors, etc., should be recorded, and each piece of equipment should be evaluated with regard to age, condition and potential performance output. Even though some of the equipment is old or out of production, local dealers, the original manufacturer, or professional engineers within established local HVAC engineering firms may be able to provide an assessment of such equipment.

Figure 4 provides a form which will assist in conducting a visual inspection of the HVAC system and its existing equipment. Some specific matters which need to be covered include: [38]

1. Determine whether the heating plant was originally designed to burn coal. If it was, then it probably is more than 30 years old and may be a good candidate for replacement.

2. Test the heating system. Even on a hot day, it can be tested by moving the thermostat above room temperature. Heat from a hot-air furnace should appear at registers within a few minutes. In a steam or hot-water system, radiators should heat up in 15-20 minutes.

FIGURE 4. EXISTING HVAC DESIGN IDENTIFICATION [7]

Identification	Estimated Air & Water Temperature Range	Estimated Equipment Age	Btu Output Range
Residential			
Non-Residential			
Forced Air System			
Radiant System			
Water			
Steam			
Electric			
Natural Convection			
Steam			
Hydronic			
Electric			
Unitary			
Number of Control Zones			
Terminal Units			
Constant Air Volume (CAV)			
Variable Air Volume (VAV)			
Fan Coil			
Induction Terminal			
Perimeter Baseboard			
Distribution Systems			
All Air Systems			
CAV			
VAV			
Single Path			
Dual Path			
Multizone			
Air and Water Systems			
Two Pipe			
Three Pipe			
Four Pipe			
All Water Systems			
Two Pipe			
Three Pipe			
Four Pipe			
Heat Pump Systems			
Air to Air			
Water to Air			
Water to Water			

3. Determine or estimate the capacity and condition of the domestic hot water heater.

4. Look for signs of leaks or rust spots around and on the bottom of the hot-water heating tank, especially where a gas flame impinges.

5. On steam or hot water heating systems, examine floor around radiators and convectors for signs of stain or rot from water leaks.

4.2.5 Space Considerations for HVAC Equipment

During the inspection tours in the existing mechanical rooms, note and record all available space for potential future installation of solar heating and replacement equipment. Photographs should be taken of the area available for the use of a prospective solar designer.

Appendix D.5.2.9 provides schematic drawings of typical solar heating systems. These should be examined to determine whether overall space is available or can be provided for such systems. In particular, space will be required for heat storage units, pumps, air handlers, and heat exchangers. The building facilities engineer should be able to provide the prospective system designer with photographs and dimensional sketches so that a decision can be reached concerning the availability of space for a particular retrofit.

In addition, where existing equipment may need to be replaced, consideration must be given to such required space. For example, if new heat exchangers are anticipated, the facilities engineer must check the adequacy of the existing space to accommodate them. A U-tube heat exchange may be required for some spaces (rather than a straight-tube type) if access is limited to only one side for cleaning or replacing the tubes.

4.2.6 Furnace/Boilers/Heating Systems [38, 39, 40, 41]

The current trend toward energy conservation and subsequent reduction in heating loads in buildings has had an effect on the efficiencies of furnaces and boilers. Older units tend to be oversized and often yield lower efficiencies. In such cases, a replacement may be desirable. Before such a decision is made, several actions should be taken to evaluate the efficiency of the existing heating components. The combustion system should be cleaned carefully and checked for leaks. The air should be allowed to enter the combustion chamber at controlled rates. The oil nozzle size may need to be reduced or the gas burner may need to be replaced if the system is to accommodate a replacement.

The required air-fuel ratio should be determined for the existing or replacement system, and adjusted for proper combustion. The O_2 and CO_2 content may be determined with an Orsat apparatus or with other flue gas analyzers such as the nondispersive infrared spectrometer for carbon dioxide, or by utilizing oxygen-specific electrodes to determine oxygen. These, coupled with the stack temperature readings, will provide data for determining

the system combustion efficiency. The final decision on system replacement generally is made on the annual operating savings that can be expected as a result of purchasing and installing a new system.

The above procedure provides only steady-state information, whereas in reality, most systems operate far from steady-state. Nevertheless, a combustion performance test should be undertaken whenever major retrofits of a building are planned in order to obtain hands-on operating experience and an immediate sense of condition of the furnace or boiler and other components of the HVAC system. The person carrying out this condition assessment should be technically experienced so that any decision made for replacement of furnace, boiler, or components is based on qualified information.

4.2.7 Evaluation of Amount of Air Leakage through the Building Envelope, Utilizing Pressurized Air [42, 43, 44, 45]

In general, simple conservation measures (such as the reduction of building air leakage) are more cost effective than solar retrofit measures and should be investigated first. Uncorrected heat losses can seriously reduce the potential gains to be expected of a solar retrofit system.

Pressurization of the space within a building, either positive or negative with respect to atmospheric pressure, is one means of gaining a quantitative measure of the air leakage of a structure. A fan, a metering station to determine air flow rate, and pressure sensors, along with temperature measurements, are needed to make the determination of leakage rate for a given pressure differential. Generally, a window or door opening can be fitted with a plywood partition through which the air required to pressurize the structure is introduced. The pressurized air will seek points of penetration, in an effort to equalize the pressure between the space and the surrounding atmosphere. The amount required to maintain the pressure differential provides an indication of the overall air leakage performance of the structure. It is possible to isolate major points of leakage by selectively taping cracks and joints during a sequence of tests. Internal air leakage paths can be identified using a fan to generate differential pressures and an infrared scanner to trace the path through the construction (see paragraph 4.2.8 below).

This technique is rather simple and not necessarily expensive (expense will vary with the complexity and detail of measurements). The results of the air pressurization test will not necessarily indicate the rate of infiltration obtained under natural (unpressurized) conditions, but, they do provide a relative measure for determining whether the structure is leaking excessively. Consult references [45] and [46].

4.2.8 Determining Paths of Leakage Using Thermography [47, 48, 49]

Sources of high heat losses can be determined through the use of thermography. This is a technique for "seeing" thermal energy radiating from the surface of a heated object. The infrared energy radiated from the object is displayed on a cathode ray tube. If a black and white cathode ray monitor is used, the intensity of the gray scale is proportional to the temperature of the object.

Within a given range, colder objects appear dark and hotter objects appear light. If a color monitor is used, the gradation of colors (red, green, blue) of the image indicates the surface temperature variations. Thus, areas of heat leakage may be detected by observing the building surface temperatures. A photograph record can be taken of the image on the screen of the monitor and surface temperatures may be inferred from the thermal image.

4.2.9 Measurement of Air Flow Rate in Air Distribution Systems by the Velocity Head Method [7]

Velocity head is measured by placing a pitot tube directly in the air steam in a duct. This should be done at several locations in the duct cross-section, each location being the center of an increment of equal area in the duct. Rectangular ducts should be divided into 12 or more incremental areas, and large round ducts into equal concentric areas, four measurements being taken within each quadrant. Pitot positions are shown in figure 5 for both rectangular and round ducts. For small, round, ducts such as 127 mm (5 in) branch ducts in a residential heating system, one velocity head measurement may be taken at the center of the duct. The average velocity is taken to be 90 percent of the centerline velocity, and the flow rate is computed using the average velocity.

Instructions are provided with the pitot tube and manometer equipment for converting velocity head to air velocity. Some manometers read directly in velocity. All of the velocity readings at one duct position are averaged to get the final average duct velocity. The air flow rate in a round duct of diameter, D_{inches}, for an average velocity, V_{avg}, is calculated as follows:

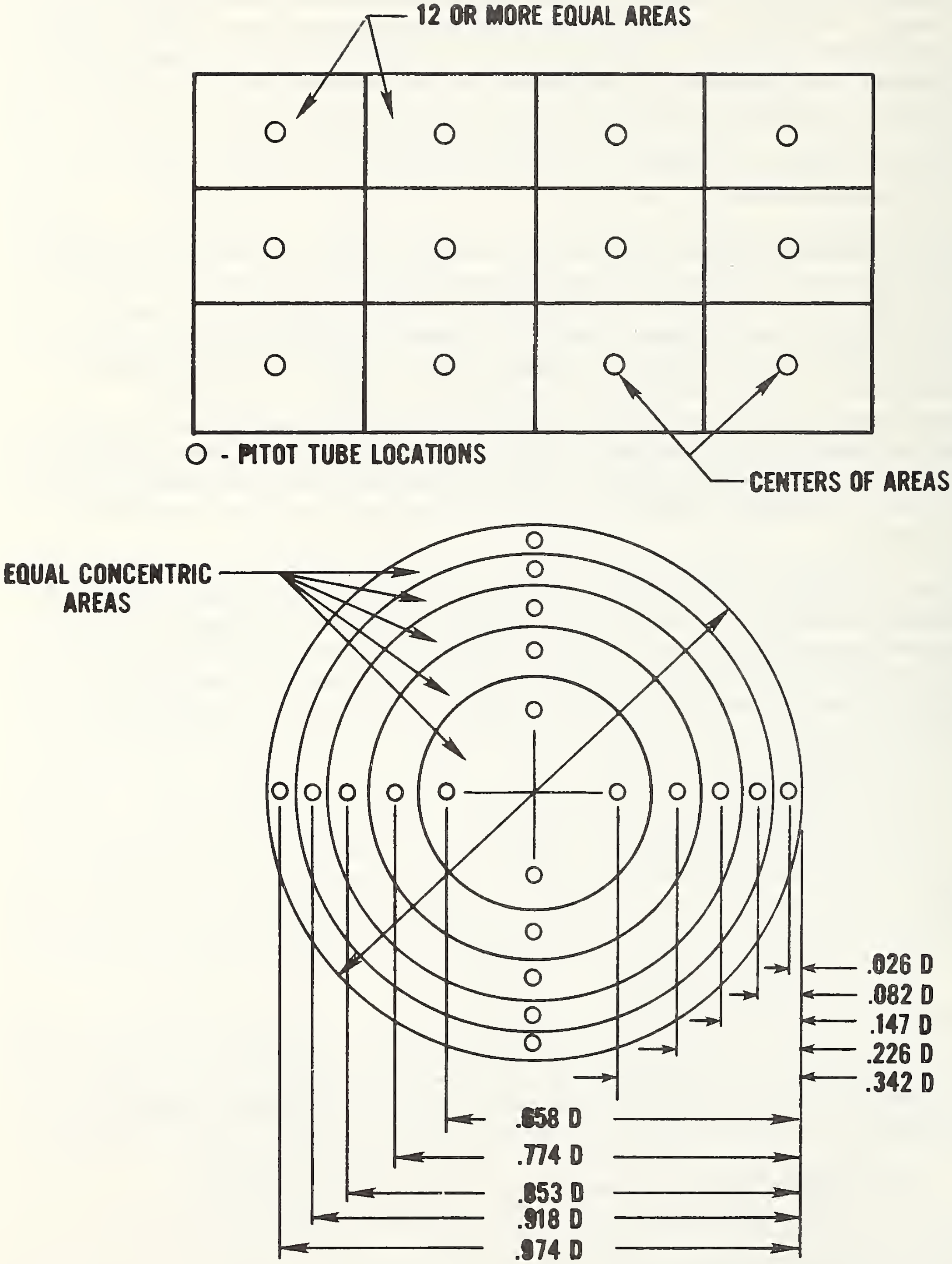
$$ACFM = \frac{V_{avg} \times D^2}{183.35}, \text{ (actual cubic feet per minute).}$$

The air flow rate in a rectangular duct with inside dimensions of A and B inches becomes:

$$ACFM = \frac{A \times B \times V_{avg}}{144}$$

The measured flow rate can be converted to flow rate at standard conditions (SCFM) as follows:

$$SCFM = ACFM \times ADR, \text{ (standard cubic feet per minute)}$$



PITOT TUBE MEASUREMENT LOCATIONS FOR RECTANGULAR AND LARGE ROUND DUCTS

FIGURE 5 [7]

where ADR (air density ratio):

$$= \frac{530}{(460 + T)\ \exp \frac{(ALT)}{27{,}000}},$$

and

T = air temperature (°F) during measurements
ALT = site elevation (ft MSL) relative to mean sea level
exp = exponential, or $e^{(alt/27,000)}$

4.2.10 Measurement of Air Flow Rate by Pressure Rise Across the Supply Blower [7]

Air flow may be determined by measuring the pressure rise across the blower, using a manometer and two static pressure probes. One probe should be placed near the blower inlet, and another down stream from the blower discharge, in a straight, constant area section of the discharge duct (see figure 6). Some fan manufacturers specify where static pressure measurements should be taken.

Estimated air flow rate in cubic feet per minute (CFM) may be determined from the manufacturer's blower performance characteristics curves for any given operating condition, consisting of: 1) discharge air temperature, 2) measured blower revolutions per minute (rpm), and 3) static pressure rise differential (or rise as determined above). See appendix D.5.2.6. Air flow at standard air conditions then may be obtained by using the conversion formula in paragraph 4.2.9 above.

4.3 HVAC PROBLEMS AND POTENTIAL IMPACT ON SOLAR RETROFIT

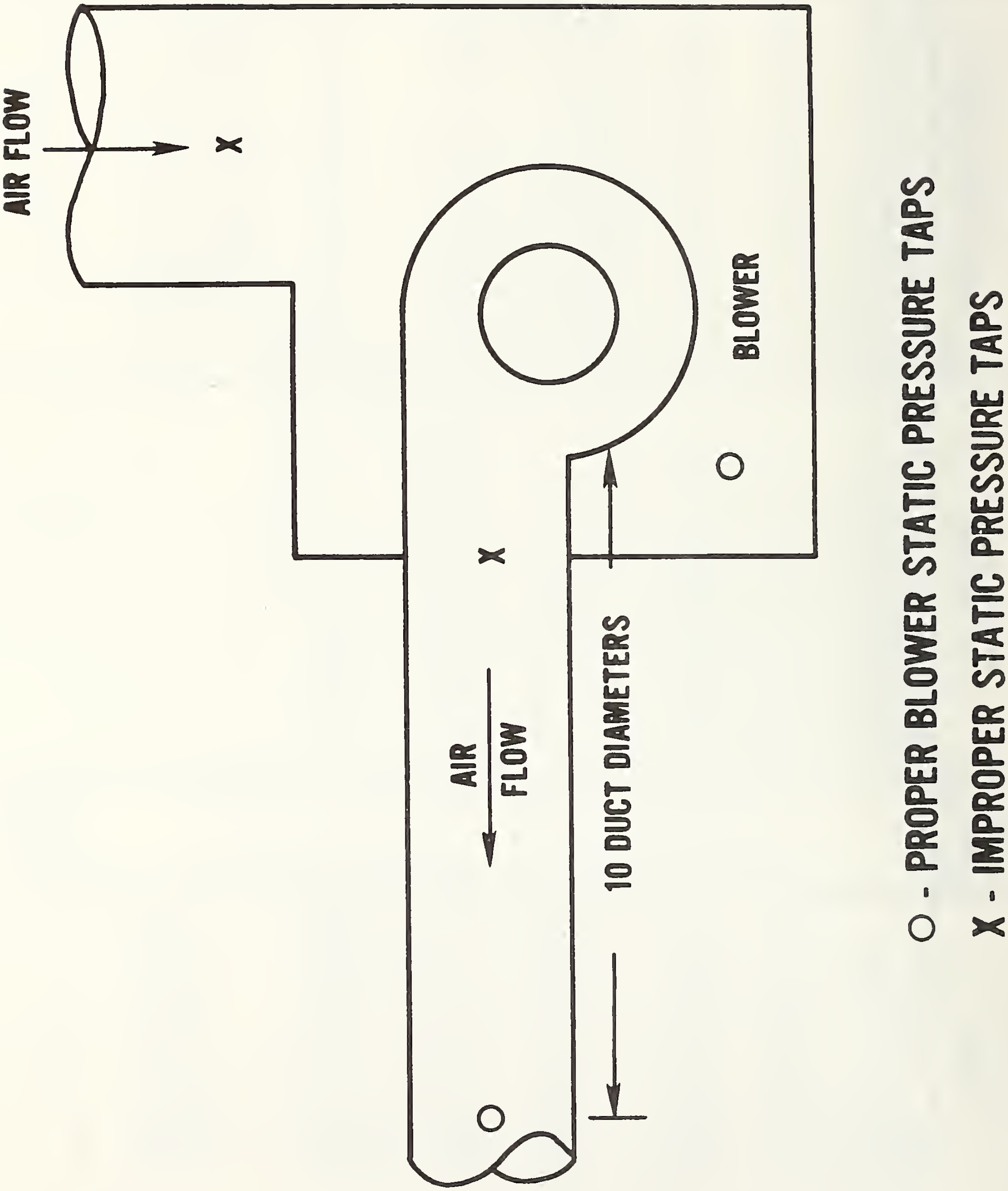
Table 11 is a checklist of typical problems for an existing HVAC system. For each problem listed, the tabulation offers possible causes, and the impact which the problem may have on a proposed solar retrofit.

TABLE 11. PRELIMINARY ASSESSMENT CHECKLIST (HVAC)

Problems	Does Problem Exist? Yes	No	Possible Causes to be Considered	Impact on Solar Retrofit
1. Non-availability of the utility bills for the past 3 years on consumption of electricity, natural gas, or fuel oil.			Lack or loss of record keeping.	If the baseline of energy consumption is not available for economic comparison, the supplier of energy can be asked to offer suggestions for estimating the energy consumed, based on their records and experience.
2. Repair and maintenance records reveal insufficient ventilation, or inadequate temperature and humidity control.			Possible causes to be determined by physical inspection and measurement.	Cause must be identified and the defects corrected before solar retrofit becomes feasible.
3. Convection system using temperature of water over 130°F.			High temperature water systems cannot effectively utilize low solar temperatures.	It will be uneconomical to retrofit the existing system with a direct solar system. A solar assisted heat pump system may be required.
4. HVAC equipment which may have exceeded its service life.			Age; obsolescence.	An economic analysis by a qualified designer is needed to determine whether it is economically feasible to replace the existing system at the time of solar retrofit.
5. Lack of performance information on individual items of HVAC equipment.			No record was kept for the equipment (name plate, serial number, etc.), and data is no longer available on nameplate.	Performance information will have to be estimated or the equipment replaced.
6. Lack of space in the mechanical equipment room or elsewhere for solar equipment.			Original system design did not allow for future expansion, or later revisions filled all available space.	It may not be feasible to adapt to a solar retrofit. Consult a solar designer.
7. Excessive air leakage through the building envelope, causing energy loss.			Faulty design or deterioration of the building structure or materials.	Air pressurization or thermography test methods should be used to determine the degree of energy loss. Energy conservation measures should be implemented before using solar retrofit.

TABLE 11. PRELIMINARY ASSESSMENT CHECKLIST HVAC - (CONTINUED)

Problems	Does Problem Exist? Yes	No	Possible Causes to be Considered	Impact on Solar Retrofit
8. Insufficient or excessive air flow rates in the duct work.			Faulty design or installation of the blower and duct work.	Flow rate may have to be corrected before adding solar retrofit.



BLOWER STATIC PRESSURE TAP LOCATIONS

FIGURE 6 [7]

5. GUIDELINES FOR PLUMBING SYSTEMS

The existing plumbing system in the building should be evaluated to determine its adequacy to support system additions or modifications resulting from a solar retrofit. This includes the water supply and drain-waste-vent (DWV) components. This section provides guidelines for the preliminary evaluation of the plumbing system. See appendix D.6 for further information to accomplish a more detailed assessment of the system.

5.1 GENERAL CONSIDERATIONS

Plumbing DWV and water supply systems can become major problems in building rehabilitation. Modification of these systems when considering solar retrofit often lead to extensive additional structural and finish work. This is because:

1. The plumbing system in an existing building may not comply with the requirements of current local codes and standards, and also may need additional equipment to meet the load imposed by added solar equipment.

2. The installation of new piping, vents, etc., required for solar equipment may be constrained by the space available and the existing piping configuration.

3. The methods of connecting new plumbing to the existing system can cause problems relative to materials and construction techniques.

5.2 ON-SITE EVALUATION GUIDELINES - PLUMBING SYSTEMS

The on-site investigation of the plumbing system consists mainly of a general examination of the plumbing components. While the emphasis should be on the plumbing components which may be affected by the solar retrofit, it is necessary also to make an overall review of the condition of the entire plumbing system. This is especially important where additional plumbing loads or significant modifications are anticipated.

5.2.1 Operation and Maintenance Record Examination

The operation and maintenance records for the past several years should be examined, and any complaints of leaks, clogging, sweating, air hammering, etc., should be noted and analyzed. Any existing additions or modifications to the plumbing systems should be noted on the construction as-built drawings if they are available. This examination should provide information concerning the adequacy of the existing plumbing system which, in turn, will assist in making the decision regarding a proposed solar retrofit.

5.2.2 Visual Inspection of Existing Plumbing System [38, 50, 51, 52, 53, 54, 55]

A thorough inspection of the plumbing system should be carried out by a qualified plumbing inspector to gain a professional opinion on the ability of the system to function in a satisfactory manner and for compliance with the local code. Physical inspection should include observations regarding the following matters:

1) Conditions which could cause an unsafe building environment:

   a. Excessively hot water (inadequate performance of temperature control devices).

   b. Explosion hazard due to inadequate temperature and pressure limiting devices.

   c. Plumbing wall construction which could allow fire spread and passage of smoke or toxic gases in case of a building fire.

   d. Water or drainage leaks, including leaks around fixture connections which could result in deterioration of structural elements or materials.

2) Conditions which could cause an unsanitary building environment:

   a. Leaks in sanitary drains and vents (which can contribute to the development of vermin, mold, odors, noxious or explosive gases, sewage accumulation, etc.).

   b. Overflowing of sewage from fixtures.

   c. Emission of sewer gas or detergent suds from fixtures.

   d. Inoperative fixtures.

   e. Inoperative domestic water heater, or inadequate supply of hot water.

   f. Poor performance of water closets.

   g. Inadequacy of potable water supply.

   h. Backflow hazard including absence or malfuction of vacuum breakers and backflow preventer.

Although the value of inspection may be diminished where portions of the system are concealed, the personal judgment of an experienced plumbing inspector can usually be relied upon for an opinion whether the existing system can be adapted to solar retrofit.

5.3 PLUMBING PROBLEMS AND POTENTIAL IMPACT ON SOLAR RETROFIT

The following checklist (table 12) may be helpful for determining the impact of typical problems on a proposed solar retrofit.

TABLE 12. PRELIMINARY ASSESSMENT CHECKLIST (PLUMBING)

Problems	Does Problem Exist? Yes	No	Possible Causes to be Considered	Impact on Solar Retrofit
1. Non-availability of water consumption and sewage bills for the past 3 years.			Lack of record keeping.	If the baseline of water supply and sewage costs is not available for economic comparison, the local municipal service organization may be asked to estimate costs based on their records and experience.
2. Repair and maintenance records reveal inadequate service due to low pressure, leaky lines, inadequate water temperature, air hammering, etc.			Possible causes are to be determined by physical inspection and measurement.	All possible causes need to be identified and the defects corrected before solar retrofit becomes feasible.
3. Excessive hot water temperature.			Inadequate or malfunctioning temperature controls.	Existing system may not be able to support the solar retrofit unless shortcomings are corrected.
4. Possible explosion hazard.			Inadequate temperature and pressure limiting devices.	Existing system may not be able to support the solar retrofit unless corrections are made.
5. Deterioration of building structure due to plumbing equipment.			Supply water or drainage leaks.	Existing system may not be able to support the solar retrofit unless corrections are made.
6. Development of mold, odors, noxious gases or the presence of vermin near the drainage systems.			Leaks in the sanitary drains or vents (see appendix D.6).	Existing system may not be able to support the solar retrofit unless the problems are corrected.
7. Gurgling or murmuring sound in the supply water system after all valves except the main water supply valve are closed.			Leaks in the supply line (see appendix D.6).	Existing system may not be able to support the solar retrofit unless the problem is corrected.
8. Excessive water pressure drop when most of the faucets are open.			Inadequate water supply pressure, or clogging of water lines (see appendix D.6).	Existing system may not be able to support the solar retrofit unless the problem is corrected.
9. Failure of water test for the drainage and vent system.			Leaky drainage and vent systems (see appendix D.6).	Existing system may not be able to support the solar retrofit unless the problem is corrected.

TABLE 12. PRELIMINARY ASSESSMENT CHECKLIST (PLUMBING) - (CONTINUED)

Problems	Does Problem Exist? Yes	No	Possible Causes to be Considered	Impact on Solar Retrofit
10. Failure of air test for the drainage and vent system.			Leaky drainage and vent systems (see appendix D.6).	Existing system may not be able to support the solar retrofit unless the problem is corrected.
11. Failure of the discharge test for siphonage of traps.			Undersized or clogged discharge pipe (see appendix D.6).	Existing system may not be able to support the solar retrofit unless the problem is corrected.

6. GUIDELINES FOR ELECTRICAL SYSTEMS

This section provides general information for the preliminary evaluation of the electrical system including its potential impact on a proposed solar retrofit. Evaluation methods covering circuit faults, insulation deterioration, and circuit breaker condition are listed and discussed. The general electrical requirements for solar retrofit also are included. Information on the more detailed evaluation techniques for electrical systems is given in appendix D.7.

6.1 ON-SITE EVALUATION GUIDELINES - ELECTRICAL SYSTEMS

The on-site investigation of the electrical system consists mainly of a general examination of the electrical components. While the emphasis should be on the electrical components which may be affected by the solar retrofit, it is necessary also to make an overall review of the condition of the entire electrical system. This is especially important where additional electrical loads or modifications are anticipated. If a system is outmoded or is grossly under capacity to accomodate the power demands of potential solar equipment (electric booster heaters, blowers, pumps, etc.), solar retrofit may not be economically feasible. Even though electrical construction drawings and specifications of the existing building are available, the existing arrangement and condition of the electrical installation should be determined.

Since most electrical wiring is concealed inside the walls, a complete inspection of all parts of the electrical system in a building may not be feasible. Some components, however, are easily checked, which will aid in evaluating the electrical shock and fire safety risks of the system compared with the requirements of the National Electrical Code and the local code. Potential problems resulting from system overloads (as new appliances and oversized fuses are installed) also should be considered.

While the evaluation methods mentioned in this section generally are recognized as being good practice, local codes and local officials should be consulted to determine whether special requirements apply to the specific building being evaluated.

6.1.1 Operation and Maintenance Records

Before a building inspection is undertaken, operation and maintenance records should be examined to identify potential problems. Incidences of power failure, insufficient lighting, electrical shock, excessive voltage drop, or short circuiting should be noted with respect to the appropriate circuit and component involved.

6.1.2 Assessing Electrical Branch Circuits [38]

One of the best techniques for assessing the condition of an existing electrical system is through visual inspection of the wiring system. It helps to determine the condition of the insulating material, as well as the quality of the connections made. It is important also to evaluate how the system is used during normal operation. The following items are considered essential:

1) Overfusing - Check for proper size fuse or circuit breaker in branch circuits. A fuse of greater capacity than originally designed will permit a potential overload of the circuit. This could result in a fire hazard.

2) Overlamping - Note the wattage of lamps compared to wattages permitted for the fixture. This is critical in confined spaces such as recessed lighting fixtures and may result in ignition of nearby combustibles.

3) Overloaded Circuits - Determine whether the proper size wire and fuses are installed to conform to the local code or to the National Electrical Code. Make note of spare circuits for potential use with solar equipment.

   Common symptoms of circuit overloading include: (1) an excessive number of 30 ampere fuses or breakers; (2) the smell of burned insulation within a panel; (3) glass top fuses which are warm; (4) discolored copper contact points under the fuses; (5) overheating of wires as evidenced by melted or brittle insulation, (6) evidence of heat discoloration due to fire around outlet boxes, switches, thermal insulation, etc.; (7) fuses which blow frequently or circuit breakers which trip frequently; and (8) presence of extensive surface mounted lamp cord extension wiring and multiple outlet cubes plugged into single outlets.

4) Type of Wiring - Determine whether the appropriate type of wiring and connectors have been used.

5) Type and Condition of Insulation - Determine whether the insulation around conductors is in satisfactory condition. Brittleness, flaking, or cracking are unacceptable, and wiring in this condition must be replaced. Examine insulation in exposed areas of the basement, in or near circuit breakers or fuse boxes, and inside outlet or switch boxes. Turn power off before removing outlet or switch plates and before probing wires.

6) Connectors - Check circuit connectors for excessive heat and power losses. Look for discolored metal, deteriorated insulation, and evidence of fire. Resistance losses cause low voltages which can impair appliances and shorten the life of components.

Visual inspection provides valuable information regarding the condition and adequacy of circuits and components, but only an experienced technician should conduct the inspection.

6.1.3 Blower Motor Horsepower Measurement [7]

The first step is to obtain the following information from each motor nameplate:

1) Rated motor horsepower
2) Number of phases
3) Cycles
4) Voltage(s)
5) Rated amperes at full load
6) Operating speed(s)
7) Type of motor and serial number
8) Power factor
9) Diagrammed electrical connections

If the motor nameplate cannot be located, obtain the above information from the manufacturer. It will be necessary to help him identify each motor by describing its size and appearance, mounting, color, components, number and location of leads, character of load (type of blower), rotational speed, number and size of belts and sheaves, and any other such information the manufacture may need.

The next step is to determine the existing operating motor horsepower (OHP) using the following nameplate and field test data:

Reading	Abbrev.	Value
Nameplate HP	NHP	
Nameplate Volts	NV	
Nameplate Amperes per phase	NA	
Measured Operating Volts	OV	
Measured Operating Amperes per phase	OA	
Measured No-Load Volts	NLV	
Measured No-Load Amperes per phase	NLA	

The above nameplate data may be read directly from the motor nameplate or may be obtained from the manufacturer as discussed earlier. The remaining data is obtained by measuring the operating volts and amperes directly at the motor, using a simple alternating current voltmeter and a snap-on type AC ammeter. Readings are needed with the motor operating at its existing normal load, and again with the motor operating while mechanically disconnected from the load.

Using the above data, the existing operating motor horsepower (OHP) may be calculated from the following relationship:

$$OHP = NHP\ (OA - 0.5\ NLA/\text{Corrected } NA - 0.5\ NLA)$$

where

$$\text{Corrected } NA = NA\ (OV/NV).$$

The nameplate and measured voltage and current values obtained for the above tabulation will be affected by the type of power supplied to the motor and the wiring system. These are discussed as follows:

1) 110 Volt, Single Phase System

   There are two power leads connected to the motor; one is hot and the other is neutral or ground. Measure the operating voltage across the two leads, and measure the operating current in either lead. The nameplate voltage and nameplate current should be similar to these measurements.

2) 220 Volt, Single Phase System

   There are three leads or wires connected to the motor, one neutral and two 110V hot wires. The voltage is measured across the two hot wires and the operating current is determined by summing the current measured in both hot wires. The nameplate voltage should be close to 220 volts, and the nameplate current is approximately double the measured current in one hot wire.

3) 220V, Three Phase, 3 Wire System

   Each of the three wires are 220V hot wires. The operating voltage is measured between any of these three wires and ground. The operating current per phase is measured in any one of the hot wires. The nameplate voltage should be close to 220 volts, and the nameplate current should be approximately three times the measured current in any one wire.

4) 220V, Three Phase, 4 Wire System

   There are three 220V hot wires and one neutral wire. The voltage is measured between any of the hot wires and the neutral. The current per phase is measured in any one of the hot wires. The nameplate voltage should be close to 220 volts, and the nameplate current should be approximately three times the measured current in any one wire.

6.2 ELECTRICAL PROBLEMS AND POTENTIAL IMPACT ON SOLAR RETROFIT

The following checklist (table 13) can be used to determine the problems in the electrical system of an existing building, and to make a preliminary determination of the impact that the problems may have on the solar retrofit.

TABLE 13. PRELIMINARY ASSESSMENT CHECKLIST (ELECTRICAL)

Problems	Does Problem Exist? Yes	No	Possible Causes to be Considered	Impact on Solar Retrofit
1. Non-availability of monthly electrical energy consumption records for the past three years.			Lack or loss of record keeping.	If the baseline of electrical energy consumption is not available for economic comparison, the power company should be asked to help estimate energy consumed, based on their records or judgment.
2. Repair and maintenance records reveal insufficient lighting, electrical hazards, excessive voltage drop, short circuiting, or power failures.			Possible causes to be determined by physical inspection and measurement.	Causes need to be identified and the defects corrected before solar retrofit is undertaken.
3. Overfusing resulting in potential circuit overloading.			Improper size of fuse or circuit breaker. Improper wire size.	Install correctly sized fuses and wiring before solar retrofit is undertaken.
4. Overlamping resulting in potential fixture overheating.			Lamps of too high wattage are used.	Correctly sized ramps should be installed before solar retrofit is undertaken.
5. Brittleness or failure of insulation.			Aged or deficient insulation around conductors.	Causes need to be identified and the defects corrected before solar retrofit is undertaken.
6. Excessive power losses.			Loose or improper connectors.	Causes need to be identified and the defects corrected before solar retrofit is undertaken.
7. Abnormal amperage for motor.			Improper selection or loading of motor.	Causes need to be identified and the defects corrected before solar retrofit is undertaken.

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APPENDIX A

Typical Forms for

Collection of Data During Preliminary On-Site Investigation

APPENDIX A

PROJECT DOSSIER [2]

The accumulation of data during the on-site investigation should be done in an organized manner. At this point it may be helpful to establish a Project Dossier. The Dossier is made up of a project notebook and a file which contains all correspondence pertaining to the project as well as collected reference material.

The forms which should be kept with the Dossier are as follows:

A. Project Notebook

1. General Building Information Form (see sample attached)
2. Member/Assembly Information Form
3. Journal Entry List
4. Contact List
5. Document List
6. Photo List
7. Sketch List
8. Specimen List

B. Project Files

1. General Correspondence
2. Journal Entry Supplements
3. Collected Documents and Citations
4. Photographs and Negatives
5. Field Reports and Sketches
6. Test Results
7. Analytical Studies
8. Evaluation Report

Form A-1

GENERAL BUILDING INFORMATION

Project #: ____________ Date: ____________ Investigator: ____________

1) Building Name: ____________

2) Street Address: ____________

3) Place: ____________

4) Country: ____________ 5) State: ____________ 6) Zip: ____________

7) Building Authority: ____________

8) Architect/Engineer: ____________

9) Builder: ____________

10) Documentation: ____________

11) Construction Dates: ____________

12) Vacancy Date: ____________

13) Site Description: ____________

14) Area: Ground Plan: ____________ Gross: ____________ Net: ____________

15) Stories: ____________

16) Structure: ____________

17) Roof: ____________

18) Exterior Walls: ____________

19) Interior Walls: ____________ 20) Fenestration: ____________

21) Floors: ____________ 22) Girders: ____________

23) Columns: ____________ 24) Basement: ____________

25) Footings: ____________

26) Supplemental Information: ____________

Form A-2

COMPONENT/ASSEMBLY INFORMATION

Project #: __________ Date: ________ Investigator: ______________________

1) Building Name: ______________________________________

2) Street Address: ______________________________________

3) Place: ______________________________________

4) Country: ________________ 5) State: __________ 6) Zip: _______

7) General Description: ______________________________________

8) Condition: ______________________________________

9) Deficiencies: ______________________________________

10) Causes of Deficiencies: ______________________________________

11) Loads: ______________________________________

12) Agents: ______________________________________

13) Materials Qualities: ______________________________________

14) Member/Assembly Properties: ______________________________________

15) Remarks: ______________________________________

____

____

Include detailed sketches of the member/assembly on the reverse side of the form. Include its location in the overall system. Scales must be shown for each sketch. Original outlines may be shown as dashed lines over the as-is state.

Form A-3

JOURNAL ENTRY LIST

JOURNAL ENTRY LIST # ________

Client: ____________________

Project: ____________________

Project Name: ____________________

Entry By: ____________________ Entry Date: ____________

Location: ____________________

Remarks: ____________________

____

____

Form A-4

CONTACT LIST

CONTACT LIST # ________

Client: ____________________

Project: ____________________

Project Name: ____________________

Name: ____________________ Title: ____________

Association: ____________________

Telephone: (   ) __________ (   ) __________ (   ) __________

Dates: ____________________

Form A-5

DOCUMENT LIST

DOCUMENT LIST # ______________

Client: ______________________________

Project: ______________________________

Project Name: ______________________ Number: __________

Description: ______________________________

Repository: ______________________ Date Mark: __________

Author/Authority: ______________________________

Remarks: ______________________________

____

Form A-6

PHOTOGRAPH LIST

PHOTO LIST # ______________

Client: ______________________________

Project: ______________________________

Title: ______________________________

Description: ______________________________

Reference #: ______________ Reference Sketch: __________

Camera: Location: ______________ Orientation: __________

Site Conditions: ______________ Date: ________ Time: ________

Photographers: ______________ Repository: __________

Remarks: ______________________________

Form A-7

SKETCH LIST

SKETCH LIST # ____________

Client: ____

Project: ____

Project Name: ______________________ Number: ____________

Subject: ____

Objective: ____

Scale: ______________________ Photo Ref. #: ____________

Date: __________ Time: __________ Sketcher: ____________

Remarks: ____

____

Form A-8

SPECIMEN LIST

SPECIMENT LIST # ____________

Client: ____

Project: ____

Project Name: ______________________ Number: ____________

Specimen: ____

Description: ____

Cond. @ Removal: ______________ Means of Removal: ______________

Loc. @ Removal: ______________ Sketch Ref. #: ______________

Photo. Ref. #: ______________ Sketch Ref. #: ______________

Remarks: ____

____

APPENDIX B

Recommended Equipment for Field Inspection

APPENDIX B

Recommended Equipment for Field Inspection [2, 7]

Camera, 110 (pocket type) with flash and film
Camera, 35mm (f3.5/50mm, or larger aperture) with flash & film
Lens, telephoto
Lens, wide angle
Tripod, camera
Recorder, Cassette (Pocket Type)
Binoculars, 7 x 35mm or better
Monocular, 8 x 20mm
Magnifier, pocket style, 4x to 10x
Mirror, inspection
Optical distance-measurer
Fiberscope, flexible
Reticle, millimeter tenths scale
Level, hand
Level, circular
Level, vial
Level, carpenter's 4 ft.
Caliper, inside/outside 5 in.
Rule, 5 in. with millimeter scale
Rule, folding 6 ft.
Tape, 50 ft.
Scale, Engineer's
Scale, Architect's
Gauge, feeler
Flashlight
Penlight
Flexilight
Calculator, pocket
Hammer, masonry
Hammer, ball peen
Awl or ice pick (to check for rot in wood)
Plumb bob
Screwdriver
Pen knife
Handbook, Engineering (pocket-type)
Project Notebook with blank forms
Clipboard with blank, ruled and graph paper
Pocket Notebook (3-3/4" x 6-3/4")
Bags, Specimen
Tape and gummed labels
Felt markers and crayons
Heavy string and thumb tacks (to check sag or bulge)
Tape, plastic
Tape, "scotch"
Cards, Marking (5" x 8")
Hairspray, Aerosol

Penetrant dyes
Glass cover slips
Glue, cyanoacrylate or comparable
Hat, safety - shoes, safety - gloves, canvas
Electrical analyzer (plug-in type)
Magnet
Matches (to check draft)
Pencil and paper
Insertion thermometer
Manometer
Pitot tube
Tachometer
Clamp on ammeter with voltage scales
Differential pressure gage

APPENDIX C

Potential Sources of Information on Buildings Being Considered for Solar Retrofit

APPENDIX C

Potential Sources of Information on Buildings Being Considered for Solar Retrofit [2]

A. At the building site (facility engineer's files):

- Original drawings and specifications, including elevations, structural, mechanical/electrical, plumbing, HVAC)
- Operation and maintenance records
- Remodeling and maintenance records
- As-built drawings
- Fire inspection details
- Photographs
- Contracting officer's files, including laboratory records, certificates of compliance with specifications, batch plant reports, inspection reports, etc.

B. Building Contractor Files:

- Original drawings
- Preconstruction data
- Construction progress reports
- As-built drawings
- Final completion report
- Progress photographs and final photographs
- Landscaping and exterior details
- Operation and maintenance records

C. Surveying Contractor Files:

- Property line survey records
- Lot location information
- Elevations

- Topographical map of site and drainage area
- Geological maps, profiles, and cross sections
- Water table elevations
- Geohydrological data
- Seismic data

D. Local Weather Bureau:

- Temperatures: maximum, minimum, and mean daily
- Precipitation: maximum, mean annual, snow accumulation
- Average humidity and range
- Solar index
- Air quality index: maximum and mean daily
- Other climatological data

E. Local and Major Federal or State Newspapers:

- Photographs (usually only final)
- Articles on design features
- Renovation or alteration articles
- Construction progress articles

F. Local and State Historical Societies and Local Library Historical Sections:

- Interior and exterior photographs
- Building records
- Historical information (past owners, past uses, important events at the building site, etc.)
- Especially check the Historic American Building Survey or the Historic American Engineering Record (U.S. Department of the Interior, Heritage Conservation and Recreation Service, Pension Building, Washington, D.C.)

APPENDIX D

Methods for the Detailed Evaluation of Systems

APPENDIX D.1

Concrete Systems

TABLE 14. CONCRETE EVALUATION TECHNIQUES

Methods	Capabilities	Degree of Sensitivity	Applications	Advantages	Limitations
Penetration					
Windsor Probe	Measures depth of penetration. Compressive strength is correlated with penetration.	Depends upon the location of the test and the precision of the calibrated depth gauge.	Concrete samples or in-situ concrete structural components.	Equipment is simple, durable and can be used by field personnel with little training.	Slightly damages a small area of concrete that is 25 to 50mm in diameter. Does not provide accurate determination of strength without a correlation curve showing correlation between depth of penetration and concrete strength.
Electrical					
Dielectric	Can determine the varying degrees of moisture content of concrete by its insulating capabilities.	Has an accuracy of $\pm$ .25% moisture content.	Has been used in the past only on laboratory samples.	The equipment is readily automated.	Equipment is very expensive and is capable of testing only for moiature content.
Electrical Resistivity	Can determine slab thickness and rebar location by measuring electrical resistance through the concrete.		Applied to in-situ pavementa and slabs.	Equipment is simple and eaay to use.	Method is limited to testing of pavements and on-grade slabs and has only specialized applications. Results are inaccurate and are affected by air entrainment, concrete den-aity, moisture and salt content, and temperature gradients.
Magnetic					
Cover meters and Pachometers	Used to locate ferromagnetic and electronically conductive componenta in concrete (both location and depth below aurface).	Can detect ferromagnetic components only within 180mm of concrete surface.	Concrete samples or in-aitu concrete structural components.	Light, portable equipment. Easy to operate and relatively inexpensive.	Portable battery equipment will not operate satisfacto-rily in freezing temperatures. Good results are obtained only if one layer of rebars is present. Will not work well with mesh reinforcement.
Rebound					
Schmidt Rebound Hammer	Measures surface hardness. Useful for determining rela-tive quality of concrete and atrength properties of con-crete from rebound distance.	Calculation of strength from calibration curve. Sensitivity of calculation depends upon accuracy of curves.	Concrete samples or in-situ concrete atructural members.	Inexpensive, fast, and can be operated by laymen.	The indication of concrete strength is not accurate, reaults are affected by condi-tion of concrete surface. Requires a correlation curve between rebound value and concrete atrength.

TABLE 14. CONCRETE EVALUATION TECHNIQUES - (CONTINUED)

Methods	Capabilities	Degree of Sensitivity	Applications	Advantages	Limitations
Acoustic					
Acoustic Emission	Monitoring of high frequency acoustic signals (stress waves) leads to detection of growing internal flaws, usually cracking.		Concrete samples or in-situ concrete structural components.	Equipment is simple and easy to operate. Data gathering requires minimal training.	Interpretation of results requires an expert. Background noise distorts results. A computer is recommended for triangulation of flaw location. Very expensive. Can be used only when the structure is loaded and when flaws are growing.
Acoustic Impact	Measuring of impact energy to detect and evaluate debonds, hairline cracks, and voids.		Concrete samples or in-situ concrete structural components.	Equipment used is portable, easy to operate, and can be automated.	Used mainly for pavements or slabs-on-grade. Most of the equipment is expensive, is in the developmental stage, and is not commonly used.
High Energy Ultrasonics	Evaluating the thickness, quality, and uniformity of a concrete by measuring the velocity of a high energy ultrasonic pulse.	Thickness measurements of concrete accurate to $\pm$ 5.0%.	Concrete samples or in-situ concrete structural components.	Measurements are very accurate. Currently, it is the only method to measure slab thickness accurately and nondestructively.	Large and heavy power supply equipment is required, data interpretations are limited to thickness measurements. Both surfaces of the concrete must be accessible.
Radiographics					
X-ray and Gamma Ray	X-rays: Density and internal structure of concrete, location of rebars and bonding stress points. Gamma rays: Location and condition of rebars, voids in concrete and grouting, determination of density and thickness of concrete.		X-ray equiment: can be used only on concrete lab samples. Gamma ray equipment: can be applied only to concrete samples or in-situ concrete structural components.	Provides a permanent record of problems on film.	Very heavy and expensive for field use with concrete. Both radiation sources are injurious to organic tissue, and the operators must be adequately shielded. Both surfaces of the concrete must be accessible.
Microwave Absorption	Application of the principle of microwave absorption to determine moisture content.	Yields values of moisture content within 30% of the mean value.	Concrete samples or in-situ concrete structural components.	Easy to use, and is moderately priced.	Low degree of accuracy, and opposite faces of specimen must be accessible.
Dynamic or Vibrstion					
Ultrasonic pulse velocity, and resonant frequency.	Measures travel time of ultrasonic pulses through concrete to determine quality and strength (modulus of elasticity, rigidity, and durability) of concrete.	The estimations of uniformity and continuity are very qualitative in nature and cannot be discussed in terms of degree of sensitivity.	Concrete samples or in-situ concrete structural components.	Excellent for determining concrete uniformity.	Skill is required to analyze results. Does not provide an estimate of strength. Equipment is expensive and requires field calibration. Background vibrations can affect results.

TABLE 14. CONCRETE EVALUATION TECHNIQUES - (CONTINUED)

Methods	Capabilities	Degree of Senstivity	Applications	Advantages	Limitations
Nuclear					
Neutron Scattering	Measurement of decreased neutron energy results in an evaluation of moisture content.	Adequacy of this method for field application on buildings has yet to be proven.	Concrete samples or in-situ concrete structural components.	An approximate method for measuring moisture content.	Equipment is very sophisticated and expensive and is not widely used. Calibration procedures have not been standardized as yet.
Neutron Activation Analysis	The cement content in concrete can be estimated by comparing the neutron activity of the test sample with a reference standard.	Accuracy is questionable. Performance of this test method in the field has yet to be proven.	Concrete samples or in-situ concrete structural components.		Equipment is expensive and complex. Calibration procedures have not been standardized as yet.
Infrared					
Infrared Test	Various passive heat patterns are identified with defects such as internal flaws, voids, and growing cracks.	At this stage of development, results are relatively unreliable.	Concrete samples or in-situ concrete structural components.	Has the potential to become a relatively inexpensive and accurate method of detecting concrete defects.	Not yet reliable, subject is being researched.
Load					
Load Testing	Application of a design load (lead, concrete, or water) to a concrete structural system to verify load carrying ability.		Applied to in-situ concrete structural systems.	Provides a high degree of reliability on a structure's ability to perform under normal loading.	Validity for long range performance is questionable. May cause cracks, distortion or even premature failure. Also requires large amounts of preparation and clean up time.
Pullout Test	Measures in-situ strength of hardened concrete.	Comparable to pull-out of cast-in-place anchors (ASTM C 900).	In-situ concrete structural components.	Fast, simple, inexpensive. Easy to apply in the field. Offers direct determination of strength parameters.	Within-test variations can be expected to occur because of lack of standardization of test procedures and equipment. Design of split-sleeve assembly is critical. Epoxy grout must cure at least 24 hours before commencing test.
Radar	Detection of substratum voids.	80% reliability of void detection.	Concrete samples or in-situ concrete structural components.	Far less destructive than "guess and drill" methods; and scanning of large surface areas can be done quickly.	Not reliable with slabs containing reinforcing mesh; very expensive; operator needs technical training.

APPENDIX D.2

Wood Systems

TABLE 15. WOOD EVALUATION TECHNIQUES

Test Method	Property or Paramater	Capability	Advantages	Limitations
Penetration Tests Pilodyn Penetrometer	Density (strength) and degree of degradation.	Can estimate approximate in-situ strength properties and degree of decay.	Equipment is portable, simple, durable, and can be used by field personnel with appropriate training.	Does not provide a precise determination of strength. Readings must be calibrated with known samples. Cannot measure decay unless it proceeds inwards from the surface. Measures only advanced stages of decay.
Electrical				
Dielectric-Type Moisture Meters	Moisture Content	Capacitance meter: Measures a change in oscillation frequency due to moisture content/ dielectric constant of the wood or change in the capacitance of the electrode as an impedance element when in contact with the specimen. Power-loss meter: Measures a loss of amplitude of an electrical wave emission resulting from amount of moisture in wood.	Both types are easy to use. There is no physical disturbance of the surface.	Useful range of the dielectric type moisture meters is from 0% to approximately 30% moisture content. Sensitive principally to the surface of the sample. Accuracy is relatively low, particularly when moisture gradient is present. Readings are affected by specimen density, chemical treatments, or decsy.
Resistance-Type Moisture Meter	Moisture Content	Moisture content of any size piece of lumber is determined by measuring its electrical resistance between two probes inserted in the lumber.	Equipment is simple and rugged. Readout is in direct units, calibrations are svailable for other grades snd species.	Yields approximate results in only the 7% to 30% moisture content range. The data sre influenced substantially by some preservatives, fire retardants, and decay.
Electrical Resistance Probe	Moisture Content	Moisture content is measured by the electrical resistance between two electrode faces on a small wooden probe inserted into a test sample.	Long-term moisture content changes can be measured by remote mesns. Can be built into the structure.	Has only been used in research, therefore in-situ use is questionable. The probes often show long time drift and hysteresis. Useful range is 7% to 35% moisture content.
Pulse Velocity				
Ultrasonic and Impact-induced Wsve Velocity Equipment (Longitudinal Wave Propagation)	Strength, Modulus of Elasticity	Major varistions in the velocity of transverse stress waves are influenced by inconsistencies in the wood that may affect strength. The density and wave velocity in a sample are measured to yield a modulus of elasticity. Strength evaluations are based on that value.	Ultrasonic equipment is is portable and readily adaptable for field use. Relatively fast measurements.	Velocity can be affected by wood characteristics that are not flaws (such as moisture content), reducing accuracy. Compressions wave procedures sre difficult to apply in-situ because of need to mechanically induce the wave.

TABLE 15. WOOD EVALUATION TECHNIQUES - (CONTINUED)

Test Method	Property or Paramater	Capability	Advantages	Limitations
Stress Wave Propagation Equipment	Strength, Modulus of Elasticity	The propagation or velocity of transverse stress waves is influenced by inconsistencies in the wood that may affect strength. The density and wave velocity in a sample are measured to yield a modulus of elasticity. Strength evaluations are based on that value.	Portable, lightweight, low cost.	Requires trained personnel to operate.
<u>Weight Test</u>				
Oven-drying	Moisture Content	Samples of wood are taken from a structural member and differentially weighed to determine moisture content (before and after drying).	Accurate results can be expected at any level of moisture content.	Requires lab test equipment. Takes considerable time.
<u>Radiographic Evaluation</u>	Grain direction, irregularities, decay, splits, knots, moisture content, insect damage, location and size of members in a floor or wall system.	Capable of measuring thickness variations over four percent in 1/2 inch thick materials (10 percent in 1 inch thick materials). Can detect internal density variations.	Provides a permanent record. Equipment for wood evaluation is lightweight, portable. Test is easy to perform.	Radiation is harmful to organic tissue and must be shielded. High initial cost. Time decays for film development. Must have access to opposite sides of test specimen.

APPENDIX D.3

Masonry Systems

TABLE 16. MASONRY EVALUATION TECHNIQUES

Material	Test Parameter	Test Method	Comments
Masonry Assemblages (Units and Mortar)	Flexural Bond Strength. Brick sampled and tested per ASTM C 67. Concrete sampled and tested per ASTM C 140. Mortar selected and tested per ASTM C 270 and ASTM C 518.	Use either the third point loading method or air bag. Specimen is loaded as a simple supported beam and is placed horizontally on its supports in the testing machine.	Testing machine must conform to requirements of Method E 4.
	Diagonal tensile or shear strength.	Masonry assemblages are tested by loading them in compression along one diagonal, thus causing a diagonal tension failure with the specimen splitting apart parallel to the direction of load.	Use a 1.2 x 1.2m (4 x 4 ft.) masonry assemblage. This method eliminates the need for a holdown force (to prevent rotation of the test specimen) as required in the racking load test prescribed in Method E 72. Three test specimens should be used.
	Modulus of Rupture	Stress test in accordance with ASTM C 67.	Used mainly for paving units.
	Compressive Strength	Compressive Test in accordance with ASTM C 67, Method E 4.	Use gypsum capping (including rapid-set gypsum).
	Water Absorption	Weighing dry and saturated conditions of test sample.	Scale should have capacity of at least 2000 g; and should have a sensitivity of at least 0.5 g for brick or 0.2% of the weight of the smallest specimen for tile.
	Saturation coefficients (for prediction of durability).	Sample is saturated by submersion in boiling water for 5 hours and cold water for 24 hours.	
	Freezing and Thawing - resistance to damage.	Repetitive cycles of wetting, freezing, drying, and weighing.	Test is continued through 50 cycles of freezing and thawing unless specimen breaks or loses more than 3% of its original weight as judged by visual inspection.
	Size	Visual measurement	Use either a steel metric (or 1 ft) scale, or a gauge or caliper with a scale ranging from 25 to 300mm (1 to 12 inches) and having parallel jaws. Of no value in determining strength or durability.
	Warpage	Visual measurement using a scale or measuring wedge.	Use either a steel metric (or 1 ft) scale, or a steel measuring wedge. The wedge shall be numbered to show the thickness of the units. Of no value in determining strength or durability.

TABLE 16. MASONRY EVALUATION TECHNIQUES - (CONTINUED)

Material	Test Parameter	Test Method	Comments
Ceramic Glazed Facing Tile and Brick	Imperviousness	Permanent blue-black fountain pen ink is applied to the glazed surface of 5 dry specimens for 5 minutes. The surface is washed and examined for stain of the finish.	Of no value in determining strength or durability. .
	Chemical Resistance	End portion of test specimen is dipped in 1 1/2 inches of a 10% solution of HCL for 3 hours. The opposite end is dipped in a 10% solution of KOH for 3 hours. Finishes are then rinsed, dried, and examined visually for changes in texture or color.	The solution must be maintained at 15 to 27°C (60 to 80°F) temperature. Of no value in determining strength. Could be useful if certain chemicals are anticipated to come in contact with the masonry.
Ceramic Glazed Structural Clay Facing Tile, Facing Brick, and Solid Masonry Units	Crazing	Autoclave crazing test. Test specimens are placed in an autoclave with 150 psi steam pressure for 2 to 2 1/2 hours. Specimens then are cooled slowly to room temperature. Then permanent blue-black fountain pen ink is applied to the glazed surfaces and a visual inspection is made to detect crazing.	Cooling should be extended over a minimum of 3 hours. Normal safety precautions should be observed concerning autoclave operation. Of no value in determining strength or durability.
	Opacity	Permanent blue-black fountain pen ink is applied to the test specimens along a 50mm (2 in) length of the edge of the finished surface. After 5 minutes, the finish is visually examined for opacity.	Of no value in determining strength or durability.
Unit Masonry	Leakage (Water Permeance)	The masonry specimen is placed in a spray test chamber which has controlled air pressure. Streams of water impinge against the exposed surface of the specimen at a rate 139 ℓ/m^2 (3.4 gal/ft^2) per hour. The air pressure is raised to 479 Pa (10 lbf/ft^2) above atmospheric pressure. The specimen then is dried and the back (unexposed) face is painted with a thin coating of white wash and the test is repeated (after the white wash dries for a minimum of 24 hours). This final test is conducted for 3 days or until a rating has been attained.	The time for appearance of visible water on the specimen is observed. The rate of leakage is observed; and from this, the water permeance in rated in accordance with ASTM E 514 classification (Class E, G, F, P, or L). This test is used mainly for a comparison of masonry specimens. It is not good for an acceptance/rejection test. Simple modifications make it useful for testing of in-situ masonry walls.

TABLE 16. MASONRY EVALUATION TECHNIQUES - (CONTINUED)

Material	Test Parameter	Test Method	Comments
Portland Cement-Lime-Sand Mortar and Masonry Cement-Sand Mortar	Compressive Strength, Water Retention, Air Content, and Efflorescence	Standard compression tests and water retention tests are used in accordance with ASTM C 91 with exceptions per BIA MI-72. Air content is determined in accordance with ASTM C 231. Efflorescence tendency is determined using the wick test described in BIA Research Report No. 15, Sec. 4.4, p. 14.	Types M, S, N, and O are included. Use type I, II, or III Portland Cement per ASTM C 150. Hydrated Lime per ASTM C 207. Sand per ASTM C 144. No air entrainment or antifreeze admixtures shall be used. Mixing and proportioning per BIA MI-72.
Masonry (Face brick, sandlime brick, concrete block, structural clay tile, and mortar) including the full assemblage.	Compressive Strength	Method B, (ASTM E 447), standard methods of test for compressive strength of masonry prisms is used to determine compressive strength of existing masonry built with the same materials as used in the test sample.	Test apparatus must conform to requirements of Method E 4. Test of building and face brick is in accordance with ASTM C 67; sandlime brick, C 67; concrete block, C140; structure clay tile, C 67; mortar, Method C 109.
		A minimum of three test prisms are built with like materials (same as in-situ). No reinforcement is used (except metal ties).	Reliability of test results is uncertain because of the unlikely event that test materials are exactly the same as in-situ materials.
		Compressive strength is determined from 7-day and 28-day tests, and Young's modulus can be determined in accordance with method E 111.	
	Structural soundness of units, bond with mortar, and to determine whether cells are are filled.	<u>Hammer Test</u> Lightly tap the masonry unit with a hammer. Listen to resonant sound. A very experienced evaluator might be able to determine the condition by the sound.	This test requires an experienced person with a good sense of hearing and a delicate touch. It is an unsophisticated test with questionable results. Test cores may be needed to validate findings.

TABLE 16. MASONRY EVALUATION TECHNIQUES - (CONTINUED)

Material	Test Parameter	Test Method	Comments
Masonry (Cont.)	Location and Uniformity of the inner cell grout and wall thickness.	<u>Probe Holes</u> Penetrate the area of investigation with a small masonry bit and probe the hole with a stiff wire.	Small holes may be patched easily. Surface damage is only minor.
Masonry Units and Mortar (including the Assemblages)	Continuity (voids or cracks), and estimation of compressive strength.	<u>Low Frequency Ultrasonics</u> Soniscope and two transducers are used. Transmitter and receiver are placed on opposite ends of the masonry units. Low frequency ultransonic sound waves are transmitted. Travel time and relative strength of transmitted signals are measured. Voids or cracks in units will weaken the signal. Compressive strength can be estimated by correlation of pulse velocity thru units and mortar with compressive strength of cores and prism that were removed from the wall and tested.	This equipment usually is available only through specialized consultants and requires operators and evaluators who are very experienced with testing of masonry. The cost may be prohibitive for routine investigations.
	Location of voids and/or reinforcement.	<u>Gamma Radiography</u> The gamma source and x-ray film are placed on opposite sides of the test specimen. After exposure of the film for several minutes, the film is processed and read. Voids show on the film as dark irregular patches. Reinforcement shows as a light area on the film.	Access to two sides of the test specimen is required. Extensive safety procedures are required due to the health hazard of gamma ray exposure. The cost could be prohibitive for routine projects. It is used mainly for specialized cases such as distressed precast masonry units when a record is needed for possible litigation.
	Location of steel reinforcement.	<u>Pachometer</u> The pachometer is a magnetic detector. The operation is based on the principle that a ferromagnetic component (such as steel reinforcement) will cause a variation in the magnetic field induced into the masonry (a non-magnetic medium).	The surface of the masonry units is scanned with a probe. Readings indicate location, size, and depth of reinforcement. This test is used only for light reinforcement. If both joint and cell reinforcement are used, results are difficult to interpret.

APPENDIX D.4

Metal Systems

TABLE 17. METAL EVALUATION TECHNIQUES

Method	Principle of Operation	Properties Sensed Or Measured	Defects Detected	Typical Applications	Advantages	Limitations
Visual/Optical	Special devices (borescopes, fiber optics, panoramic cameras, etc.) can be used to examine surfaces inaccessible to the naked eye. Magnifiers can be used to detect flaws too small to be seen by the naked eye.	Material characteristics open to a surface.	Surface flaws (cracks, voids, holes, gouges, fabricating discontinuities, corrosion, pits, and other iregularities).	Surfaces of all metals.	Permits examination of hidden surfaces (if access is available).	Detects only defects visible to the eye. Limited to detection of surface flaws only.
Liquid Penetrant	Liquid penetrant containing dye is drawn into surface defects by capilliary action.	Material separations open to a surface.	Surface cracks, laminations, poor bonding, gouges, porosity, laps, seams, stress cracks, fabricating discontinuities.	Used on non-magnetic metals. Used with castings, forgings, weldments, and components subject to fatigue or stress-corrosion cracking.	Allows inspection of complex shapes in one single operation. Inexpensive. Easy to apply. Portable.	Will detect only defects open to the surface. It is messy. Irrelevant indications occur. Results are dependeot on operator's ability to interpret results. Temperature of specimen, penetrant drain time, emulsifier soak and drain time, drying temperature, and developing powder dwell time must be controlled carefully to get true indications.
Ultrasonic	Vibrations above 20,000 Hz are introduced into metal sample. Waves are reflected or scattered by discontinuties.	Anomalies in acoustic impedence.	Cracks, voids, porosity, laps, segregated inclusions, poor brazing or bonding. Will detect botb surface and subsurface defects.	Thickness gaging. Material inspection of castings, forgings, and extrusions. For all metals.	Locates small discontinuties. Portable. Instant results. Accurate measure of thickness.	Sensitivity is reduced by rough-surfaced parts. Odd-shaped pieces are hard to analyze. Requires skilled operator. Depend on operator's ability to interpret results and on orientation of the defect. Must couple transducer to surface of specimen carefully.
Magnetic Particle	Magnetic particles are attracted to magnetic lines of leakage force and where breaks in the lines of force occur.	Anomalies in magnetic field flux at surface of test sample.	Cracks, seams, laps, voids, porosity, and inclusions.	Surface and slightly subsurface inspection of parts sensitive to magnetization.	Simple, inexpensive, senses flaws down to 1/4 inch below surface as well as surface flaws.	Not applicable to non-magnetic metals or materials. It is messy. Careful surface preparation is required. Irrelevant indications often occur. Depends on the operators ability to interpret results. Demagnetization after inspection may be necessary.
X-ray or Gamma ray	The attenuation of x-rays is affected by the density of the test specimen. Voids, or low-density areas show as dark indications on the x-ray film.	Inhomogeneities in thickness, density, or composition.	Voids, porosity, inclusions, and cracks.	Used on castings, forgings, weldments, and assemblies to check for fatigue, thickness gauging, internal flaws, etc. For all metals.	Detects both internal and external flaws. Portable. Provides a permanent record on x-ray film.	High cost. Heavy. Health hazard. Not sensitive to defects less than about 2% of the total thickness of the specimen. Complex shapes are difficult to analyze. Internal forging cracks can only be detected if grain flow is aligned with radiation beam.

TABLE 17. METAL EVALUATION TECHNIQUES - (CONTINUED)

Method	Principle of Operation	Properties Sensed Or Measured	Defects Detected	Typical Applications	Advantages	Limitations
Eddy Current	The impedance of a probe coil is measured constantly. The coil is placed in contact with the metal specimen. The coil impedance changes in direct relationship with the specific material properties and constituent variations.	Anomalies in electric conductivity and, in some cases, magnetic permeability.	Surface finish, discontinuties, dimensions, cracks, seams, variations in alloy composition or heat treatment.	Used to evaluate condition of wire, tubing, local regions of sheet metal and alloy sorting. Used for thickness gauging. For electrically conductive or magnetically permeable metals.	Moderate cost. Readily automated. Portable. Permanent record available if needed. Can be adapted to many comparative analyses.	Useful on conductive materials only. Shallow penetration. Reference standards often are necessary. No absolute measurement-only qualitative comparison.
Coupon	Stress-strain relationship. Tension or compression tests.	Stress-strain.	Yield strength, yield point, tensile strength, elongation, modulus of elasticity, compressive.	Die castings, forgings, structural shapes, malleable iron, powdered metals.	Gives fast, accurate results of physical and mechanical values.	Test is destructive since a sample must be removed to be tested.

APPENDIX D.5

HVAC Systems

D.5 HVAC SYSTEMS

D.5.1 GENERAL

This section covers methods which supplement the information derived from the preliminary evaluation discussed in section 4. Methods outlined in this section include those procedures which are more detailed or sophisticated than those given under section 4. Accordingly, they will require a greater degree of expertise, understanding, judgment, and time. They should be conducted after the preliminary procedures of section 4, have been completed and the HVAC systems are still considered to be sound candidates for solar retrofit.

D.5.2 GUIDELINES

D.5.2.1 Determining Infiltration Rate Using Tracer Gas [42, 46]

The actual infiltration air exchange rate within a structure can be determined through the use of a tracer gas which is released into the space to be measured. The concentration of the gas then is monitored over a period of time, and the exchange rate can be expressed through the following relationship:

$$I = - {}^{1}/t \ \ln \left({}^{c}/co\right)$$

where: I = infiltration rate as air volume changes per hour

t = time

co = concentration of tracer gas at time zero (beginning of test)

c = concentration of tracer gas at a specific time within the test period.

When the natural logarithm (ln) of the relative concentration (${}^{c}/co$) is plotted as a function of time, the rate of infiltration (I) is the negative slope of the best fit line through the data points. Several tracer gases, such as carbon dioxide, helium, nitrous oxide, ethane, methane, and others, have been used as indicators of concentration of decay due to infiltration. Currently one of the most popular is sulfur-hexafluoride (SF_6). Samples of the air within the structure are taken and analyzed on the spot or stored in sample bags during the test and later analyzed.

The tracer gas technique is probably the best measure of natural infiltration because it does not introduce any unnatural constraints for making the determinations (other than some form of forced air circulation within the space to maintain mixing of tracer gas and air). The use of sulfur-hexafluoride requires very small amounts of harmless gas (generally on the order of 10-50 parts per billion) thus altering to a negligible extent the composition of the air. At infiltration rates of greater than three air changes per hour, the tracer gas technique may give unreliable results because of the introduction of larger

amounts of unmixed air causing significant scatter in the data. Although higher rates of exchange seldom are encountered, where they do occur, greater care in mixing and more frequent sampling may be required.

D.5.2.2 Determining Humidity with Color Changing Agents [56]

The color change humidity indicator is a simple, inexpensive device for monitoring relative humidity within a structure. One such indicator uses cobaltous chloride as the basic ingredient for indicating the relative humidity. Cobaltous chloride is exposed to the atmosphere on blotting paper, and when equilibrium is reached, the color of the ingredient changes. Plug-type indicators may be used to indicate the relative humidity in wall cavities and in enclosed roof ceiling cavities. Color change indicators may be used also to monitor the relative humidity in occupied spaces.

The available relative humidity range for various chemicals is from 10 to 80 percent. It is possible to measure relative humidity within five percent of the published equilibrium point. A 10°F change in temperature will affect indicator accuracy by only 2-1/2 percent. Because the equilibrium point varies with the specific chemical used, a particular chemical is accurate only at a specific humidity (not a range). The accuracy of the indicator may be affected by temperature changes and long-term exposure to high humidity, high temperature, or direct sunlight. Direct contact with water also will cause the chemicals to leach out of the paper and thus lose their calibration.

D.5.1.3 Determining Humidity with an Electric Hygrometer [57]

With a change in humidity, many substances absorb or give up moisture and exhibit changes in electrical impedance. Sensors are available which have dual electrodes or windings that are electrically separated by a thin film of binder material containing a salt solution (such as lithium chloride). Means are provided for measuring the AC electrical impedance between the electrodes through the salt film. Since the impedance through the salt responds to changes in relative humidity and temperature, accurate indications of relative humidity can be obtained.

These electrical impedance hygrometers are relatively sensitive to humidity changes and are adaptable for remote read-out. Accuracy is in the order of ± 1.5 percent RH and elements are available to cover the range from 10 to 90 percent RH. Because the electrical impedance hygrometer is susceptible to damage by air contaminants and water, frequent calibration checks are required. Nevertheless, elements may be placed in remote places for monitoring changes in relative humidity under high humidity conditions.

D.5.1.4 Determining Heating System Efficiency by Using Electric Co-Heating [58]

Electric co-heating is a technique used to determine the net efficiency of a heating system (a furnace, for example) within a house. Several portable, thermostatically controlled, and metered electric heaters are distributed throughout the house. The furnace is turned off, and only the electric

heaters are used to measure the total heat consumed in the house. Next, the furnace is turned on and cycled manually at an arbitrary rate (for example, four minutes on and sixteen minutes off) for about three hours. Throughout the procedure, the indoor temperature is kept constant by appropriate control of the heat provided by the electric heaters. Finally, the furnace is turned off and the electric heaters again carry the full load to obtain a check on the total load.

The indoor temperature is recorded and periodic measurements of the outdoor temperature are taken. Also, the air infiltration rate (through cracks in walls, etc.) is monitored using tracer gas techniques. The following steps are then used to calculate the net system efficiency:

1) The heat load, including air infiltration, is determined through the power consumed by the electrical heaters operating alone.

2) The portion of the heat load supplied by the furnace is determined from the difference between the measured total load and the measured electrical power consumed by the heaters while operating in conjunction with the furnace.

3) The efficiency is calculated by dividing this difference by the average energy consumed by the furnace.

The electric co-heating technique also may be used to evaluate fireplace efficiency, and to determine the fraction of the heating load needed for the individual rooms in the dwelling. Unlike some methods of efficiency evaluation, electric co-heating cancels out distribution heat losses (through ducts, etc.). In other words, the efficiency calculation includes only the heat that benefits the living space. As a result, this method distinguishes between heating system efficiency and the house's envelope performance. Electric co-heating, however, is still in the development stage. For example, it is not practical for use with structures having a large number of rooms because of the present difficulty in monitoring the infiltration losses and the power consumed by the individual rooms.

D.5.2.5 Determining Wall Thickness of Containment Vessels [59]

It is possible to use ultrasonic techniques to determine the thickness of materials to obtain an indication of wear and deterioration. The pulse-echo ultrasonic thickness technique is recognized as an accurate method of measuring thickness of materials when the velocity of the pulse wave is known. Ultrasonic transducers have been developed that will allow the determination of piping and tubing wall thicknesses (as well as other forms) without physically penetrating the material. Ultrasonic pulses are generated and the time required for the pulse to be reflected back from the opposite surface is very accurately recorded. By knowing the transmission velocity of the material, and with the appropriate electronic circuitry, a digital readout can be obtained which is a direct measure of the thickness of the material. The technique has been used to evaluate large boiler installations for heat exchanger deterioration caused by corrosion.

Small transducers are available to determine thickness of closed materials without physically penetrating the surface. By scanning the surface variations, wall thickness can be determined, thus gaining an indication of deterioration.

Some distortion results from rough surfaces as the ultrasonic pulse is scattered, with a resulting lack of sharpness in the return echo. As surface curvature increases, the coupling efficiency between transducers and the material to be measured decreases, causing some loss in accuracy. Some materials have special acoustical characteristics and can cause scattering, velocity variation, and attenuation, with a resulting loss of accuracy. For these reasons, it is important that thickness determinations be made by experienced personnel.

D.5.2.6 Determining Blower Revolutions per Minute (RPM) and Horsepower (HP) to Maintain System Air Flow Rate [7]

When solar equipment is added to an existing warm air heating system, it may become necessary to add a hot water heat exchanger to the existing ductwork. This will increase system resistance and will require increased blower RPM to maintain the original air flow rate. The RPM needed to overcome the increased system resistance is determined by:

$$\frac{N_2}{N_1} = \frac{P_2}{P_1}$$

where

- P_1 is the existing system static pressure
- N_1 is the existing blower RPM
- P_2 is the new system static pressure
- N_2 is the new blower RPM required

The increased power requirements then are determined by:

$$\frac{HP_2}{HP_1} = \left[\frac{N_2}{N_1}\right]^3$$

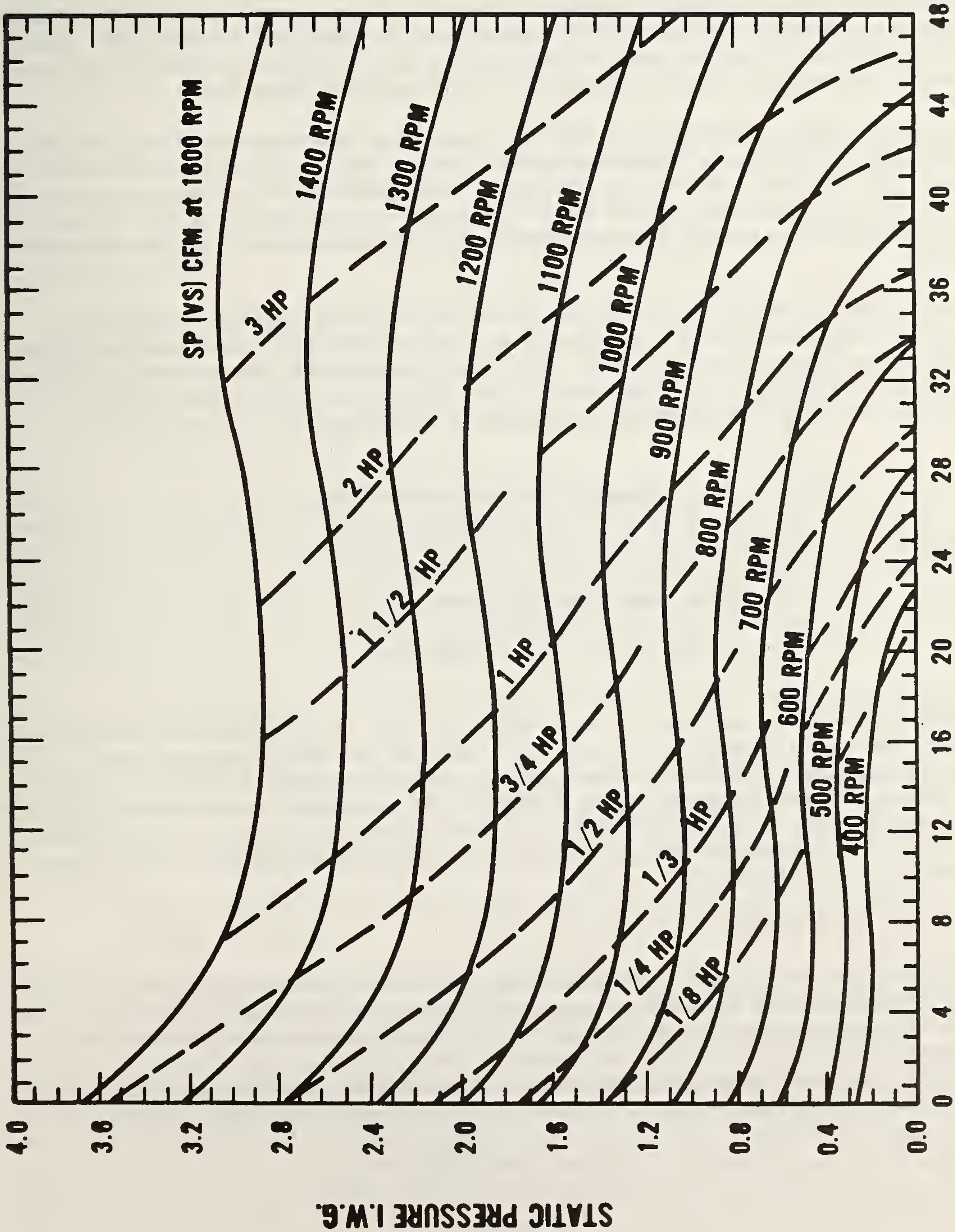
where

HP_1 represents the existing power requirements as motor horsepower

HP_2 represents the new power requirements resulting from the increased RPM

The existing blower power can be determined by using an ammeter and a voltmeter as described in section 6.1.3.

Blower manufacturers keep on file the blower performance characteristics of all blowers manufactured by them. A set of characteristic curves for a simulated blower is illustrated in figure 7. With the existing system air flow rate (CFM) and blower RPM known, the estimated existing system static



SIMULATED BLOWER CHARACTERISTIC CURVE

FIGURE 7 [7]

pressure drop may be estimated and the corresponding HP may be determined. For example, according to figure 7, the simulated blower depicted is expected to deliver 2400 CFM against approximately 1.4 inches of water system static pressure, requiring approximately 1 HP of motor power, at a blower speed of 1000 RPM. Note: Figure 7 cannot be used for any other blower. The manufacturer's specific characteristic curves must be used for the specific blower in question. Other methods for estimating the existing system CFM and system static pressure drop are discussed in sections 4.2.9 and 4.2.10.

If a new heat exchanger coil is to be added to the existing blower system, the coil manufacturer will supply data on the static pressure drop across the coil for various standard air volumes. This additional resistance may be added to the existing system static pressure to determine the new system static pressure required to determine the new blower speed and HP discussed above.

For a belt driven blower, the blower speed may be increased by changing the sheaves (pulleys) on the blower and/or the motor in accordance with the following inverse relationship. The same relationship may be used to determine the existing blower RPM except that measuring RPM directly with a tachometer or a strobe light is much more accurate.

$$\text{Blower RPM} = \text{Motor RPM} \times D_1/D_2$$

where

D_1 is the motor pulley pitch diameter

D_2 is the blower pulley pitch diameter.

Direct drive fans may have a multi-speed motor. It then will be necessary to check the motor nameplate to determine whether the motor is multi-speed, and at which speeds it will operate. Also check the wiring of the motor against a wiring diagram located on the nameplate or equipment to determine whether the motor speed can be increased. If the blower speed cannot be increased, an additional booster fan can be added in series with the existing fan to restore system flow rate.

D.2.5.7 Determining Duct Velocity [7]

The air flow requirements of a cooling system are approximately 400 standard CFM (SCFM) per ton of cooling capacity. Since the air flow requirements for a cooling system are greater than the air flow requirements for a heating system, the retrofitting of an existing forced air heating system to include cooling may pose some problems with duct size. Air duct velocities can be determined from the system CFM and duct dimensions by a simple formula:

$$V = \frac{ACFM}{A}$$

where ACFM is the actual system air flow rate in ft^3/min and A is the duct cross-sectional area in ft^2. Table 18 shows recommended and maximum air velocities for low pressure residential duct systems. If the duct velocity exceeds the values listed in table 18, the ducts are undersized and should be enlarged, or the system duct work redesigned to accommodate the increased air volume required for cooling. Note - the table is for low pressure duct work. Medium and high pressure duct work will tolerate greater velocities.

D.5.2.8 Determining Performance of Heating Coils [7]

This section covers the performance of central heating coils, zone heating coils (fan coil units, reheat units), natural convective heating equipment, and radiant heating equipment.

The performance of an existing forced air heating coil is limited by the following factors:

1) Supply water temperature
2) Water flow rate
3) Return air temperature
4) Air flow rate
5) Coil construction - materials, number of passes, etc.
6) Coil surface area.

Return air temperature is governed by space comfort conditions and is not appreciably alterable. Increasing the water flow rate has limited effect on full coil capacity, as shown in figure 8. For a given heating coil construction and surface area, equivalent heat output can be obtained with decreasing supply water temperature by increasing the air flow rate, as shown in figure 9. Increasing air flow rate, however, introduces a number of potential problems. This method is satisfactory only if:

1) The supply air temperature does not fall below a reasonable level for room comfort;

2) The existing blower and/or the existing air supply terminal can be modified economically to provide for the increased flow rate;

3) The potential increased noise is not objectionable;

4) The increased air velocity does not create objectionable drafts within the space.

If these criteria cannot be met, it will be necessary to increase the heat exchange area or consider installing a higher temperature solar heating system (such as an evacuated tube or solar assisted heat pump system).

Additional heat transfer surface can be provided in a number of ways, depending upon the equipment. It is easiest to either replace the coil in an existing unit or add an additional coil to the unit. This will depend upon the replacement coils available for the unit, and whether or not space is available for the inclusion of an additional coil or a larger coil.

TABLE 18. RESIDENTIAL DUCT AIR VELOCITY [7]

	Recommended Velocity FPM (feet per minute)	Maximum Velocity FPM
Main Trunk Duct	700-900	1000
Branch Ducts	600	800
Branch Riser	500	800
Outdoor Air Intake	500	600
Return Air Ducts	700	900
Air Collector Manifold Ducts . . .	700-900	1000
Air Collector Riser Ducts	800	1000

COMMERCIAL DUCT CLASSIFICATIONS

	Velocity	Static Pressure
Low Pressure	< 2000 fpm	SP < 2 in W.G.
Medium Pressure	> 2000 fpm	2 in < SP < 6 in
High Pressure	> 2000 fpm	6 in < SP < 10 in

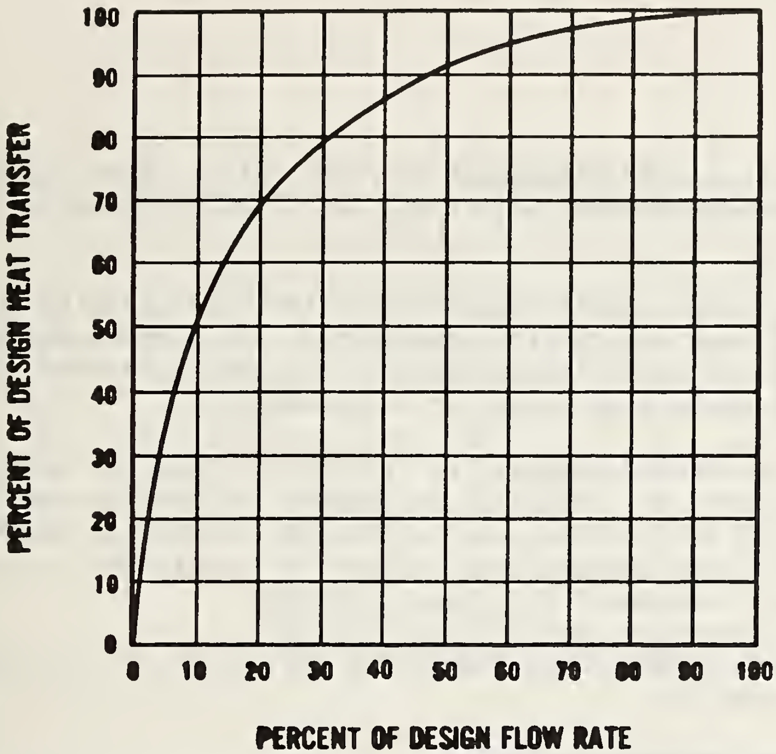


FIGURE 8 [7]

EFFECTS OF WATER FLOW RATE ON COIL HEAT TRANSFER FOR 20°F WATER TEMPERATURE DROP AT 200°F WATER SUPPLY TEMPERATURE

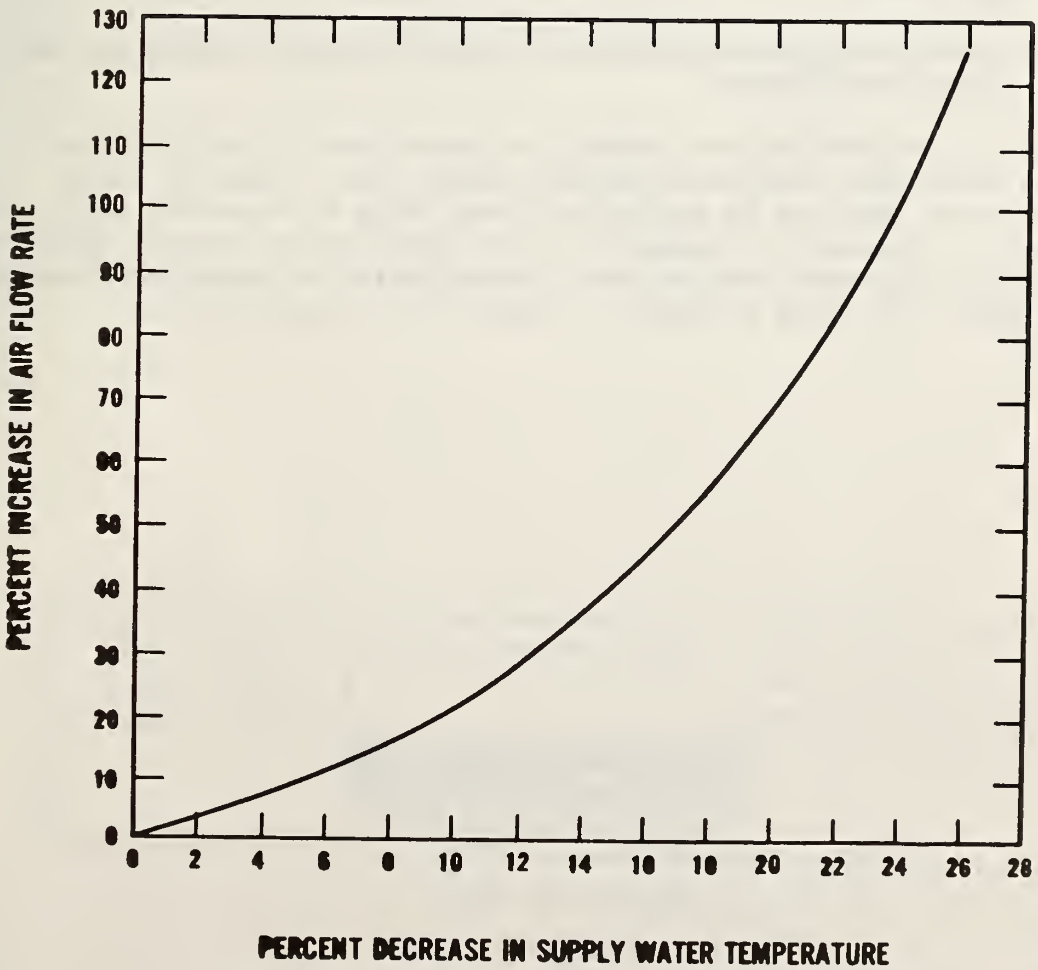


FIGURE 9 [7]

INCREASE IN AIR FLOW REQUIRED TO MAINTAIN CONSTANT HEATING COIL OUTPUT WITH DECREASE IN SUPPLY WATER TEMPERATURE

Another alternative is to add additional fan/coil units. Each zone should be analyzed, to determine whether additional units can be placed in the zone.

Table 19 shows the characteristic change in heating coil capacity with changing supply water and return air temperatures, all other factors remaining constant. The table again illustrates how coil heat transfer capacity is greatly reduced with decreasing supply water temperature.

This illustration is intended to show the limitations inherent with coil performance characteristics. Detailed performance information must be obtained from catalogs or from the manufacturer of the coil or heating unit, so that a qualified system designer may analyze the possibility of utilizing existing heat transfer equipment in a solar retrofit.

The performance of existing natural convective and radiant heat transfer equipment is influenced by:

1) Supply water temperature
2) Water flow rate
3) Room air or radiant surface temperature
4) Unit construction
5) Surface area

Radiant units additionally are influenced by their surface emissivity, but this effect is not significant.

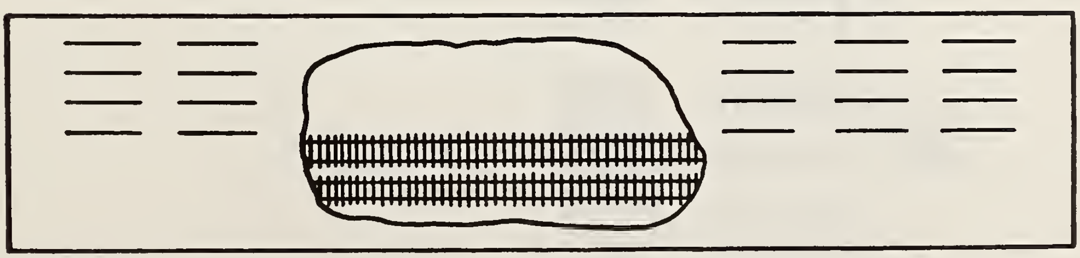
The major factor influencing the capacity of these units is supply water temperature, with water flow rate playing a minor role. Table 20 shows correction factors that can be applied to these units to determine their off-design capacity. However, it probably will be necessary to replace existing units with ones of greater surface area. Substitution of single row baseboard units with double row units as shown in figure 10 is one convenient alternative.

ENTERING AIR TEMP F	ENTERING WATER TEMPERATURES, F													
	95	100	110	120	130	140	150	160	170	180	190	200	210	220
40	.458	.500	.583	.666	.75	.833	.917	1.00	1.08	1.16	1.25	1.33	1.42	1.50
50	.375	.417	.500	.583	.666	.75	.835	.917	1.00	1.08	1.16	1.25	1.33	1.42
60	.292	.333	.417	.500	.583	.666	.750	.835	.917	1.00	1.08	1.16	1.25	1.33
70	.208	.250	.333	.417	.500	.583	.666	.750	.835	.917	1.00	1.08	1.16	1.25
80	.125	.167	.250	.333	.417	.500	.583	.666	.750	.835	.917	1.00	1.08	1.16

NOTE: These Factors as based on constant GPM.

CAPACITY CORRECTION FACTORS FOR ENTERING CONDITIONS
OTHER THAN 60 F EAT AND 180 F EWT

TABLE 19 [7]



DOUBLE ROW BASEBOARD UNIT

FIGURE 10 [7]

Steam Pressure (Approximate) Gage (Vacuum)		Absolute		Temp. of Heating Medium Steam or Water		Cast Iron Radiators Room Temp. F (°C)					Convectors Inlet Air Temp. F(°C)					Finned Tube Inlet Air Temp. F (°C)					Baseboard Inlet Air Temp. F (°C)				
						80	75	70	65	60	75	70	65	60	55	75	70	65	60	55	75	70	65	60	55
In.Hg.	(kPa)	psi	(kPa)	F	(°C)	(26.7)	(23.9)	(21.1)	(18.3)	(15.6)	(23.9)	(21.1)	(18.3)	(15.6)	(12.8)	(23.9)	(21.1)	(18.3)	(15.6)	(12.8)	(23.9)	(21.1)	(18.3)	(15.6)	(12.8)
22.4	(-75.8)	3.7	(25.5)	150	(65.6)	0.39	0.42	0.46	0.50	0.54	0.35	0.39	0.43	0.46	0.50	0.36	0.42	0.46	0.51	0.57	0.38	0.42	0.45	0.49	0.53
20.3	(-68.9)	4.7	(32.4)	160	(71.1)	0.46	0.50	0.54	0.58	0.62	0.43	0.47	0.51	0.54	0.58	0.45	0.49	0.53	0.59	0.64	0.45	0.49	0.53	0.57	0.61
17.7	(-59.9)	6.0	(41.4)	170	(76.7)	0.54	0.58	0.62	0.66	0.69	0.51	0.54	0.58	0.63	0.67	0.53	0.57	0.61	0.67	0.72	0.53	0.57	0.61	0.65	0.69
14.6	(-49.6)	7.5	(51.7)	180	(82.2)	0.62	0.66	0.69	0.74	0.78	0.58	0.63	0.67	0.71	0.76	0.61	0.65	0.69	0.75	0.81	0.61	0.65	0.69	0.72	0.78
10.9	(-37.2)	9.3	(64.1)	190	(87.8)	0.69	0.74	0.78	0.83	0.87	0.67	0.71	0.76	0.81	0.85	0.69	0.73	0.78	0.84	0.89	0.69	0.73	0.78	0.82	0.86
6.5	(-22.0)	11.5	(79.3)	200	(93.3)	0.78	0.83	0.87	0.91	0.95	0.76	0.81	0.85	0.90	0.95	0.77	0.81	0.86	0.92	0.97	0.81	0.86	0.92	0.95	1.00
psi	kPa																								
1	(6.2)	15.6	(107.6)	215	(101.7)	0.91	0.95	1.00	1.04	1.09	0.90	0.95	1.00	1.05	1.10	0.91	0.94	1.00	1.06	1.11	0.91	0.95	1.00	1.05	1.09
6	(41.9)	21.0	(143.3)	230	(110.0)	1.04	1.09	1.14	1.18	1.23	1.05	1.10	1.15	1.20	1.26	1.03	1.08	1.14	1.19	1.24	1.04	1.09	1.14	1.19	1.25
15	(104.3)	30.0	(205.6)	250	(121.1)	1.23	1.28	1.32	1.37	1.43	1.27	1.32	1.37	1.43	1.47	1.20	1.26	1.31	1.37	1.43	1.22	1.27	1.32	1.37	1.43
27	(187.3)	42	(288.6)	270	(132.2)	1.43	1.47	1.52	1.56	1.61	1.47	1.54	1.59	1.67	1.72	1.38	1.44	1.50	1.56	1.62	1.43	1.47	1.52	1.59	1.64
52	(360.7)	67	(462.0)	300	(148.9)	1.72	1.75	1.82	1.89	1.92	1.85	1.89	1.96	2.04	2.08	1.67	1.73	1.79	1.86	1.92	1.75	1.82	1.89	1.92	1.96

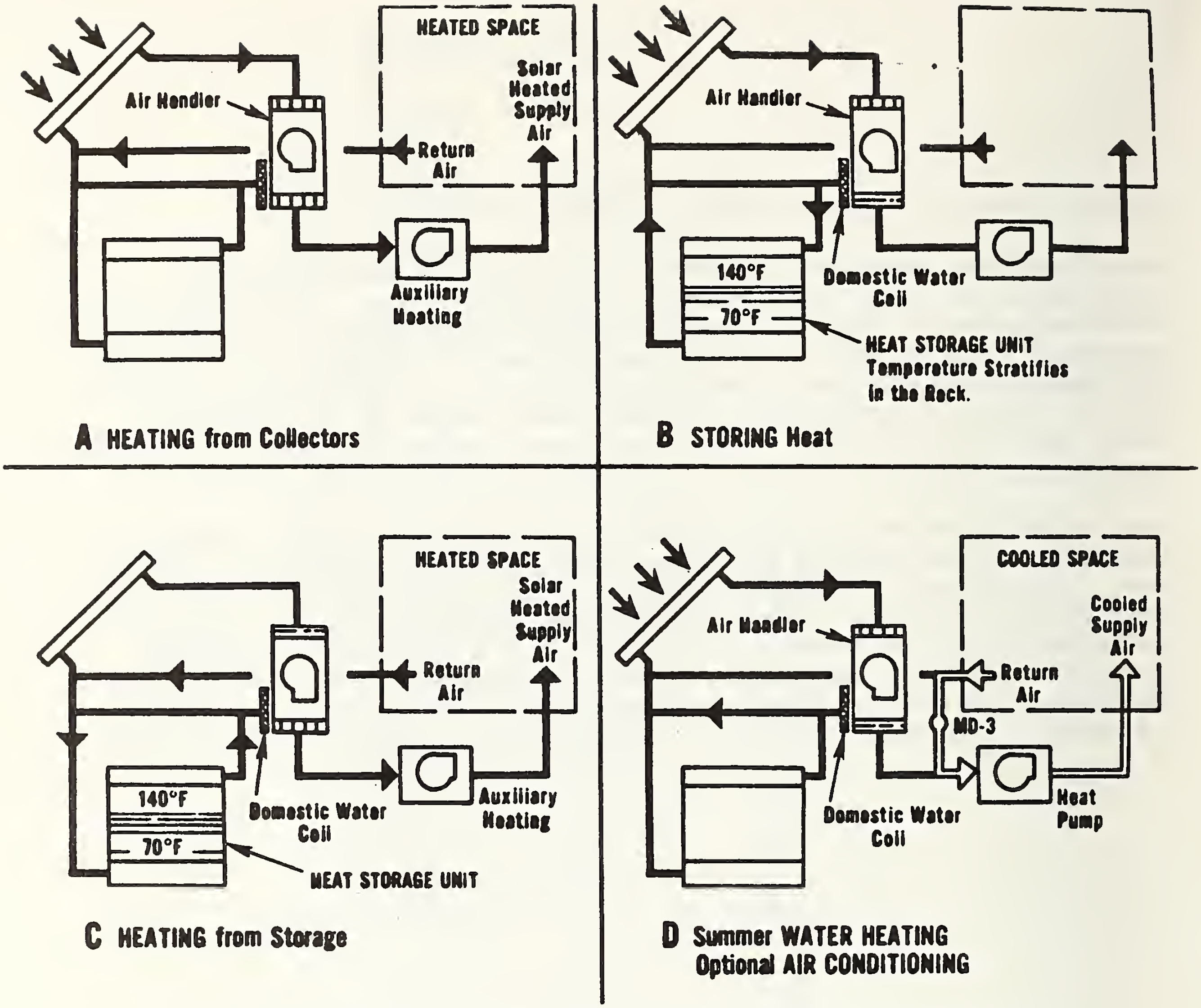
CORRECTION FACTORS FOR OFF DESIGN PERFORMANCE OF VARIOUS
NATURAL CONVECTIVE AND RADIANT HEAT TRANSFER EQUIPMENT

TABLE 20 [7]

D.5.2.9 Solar Heating and Cooling Schematic Drawings

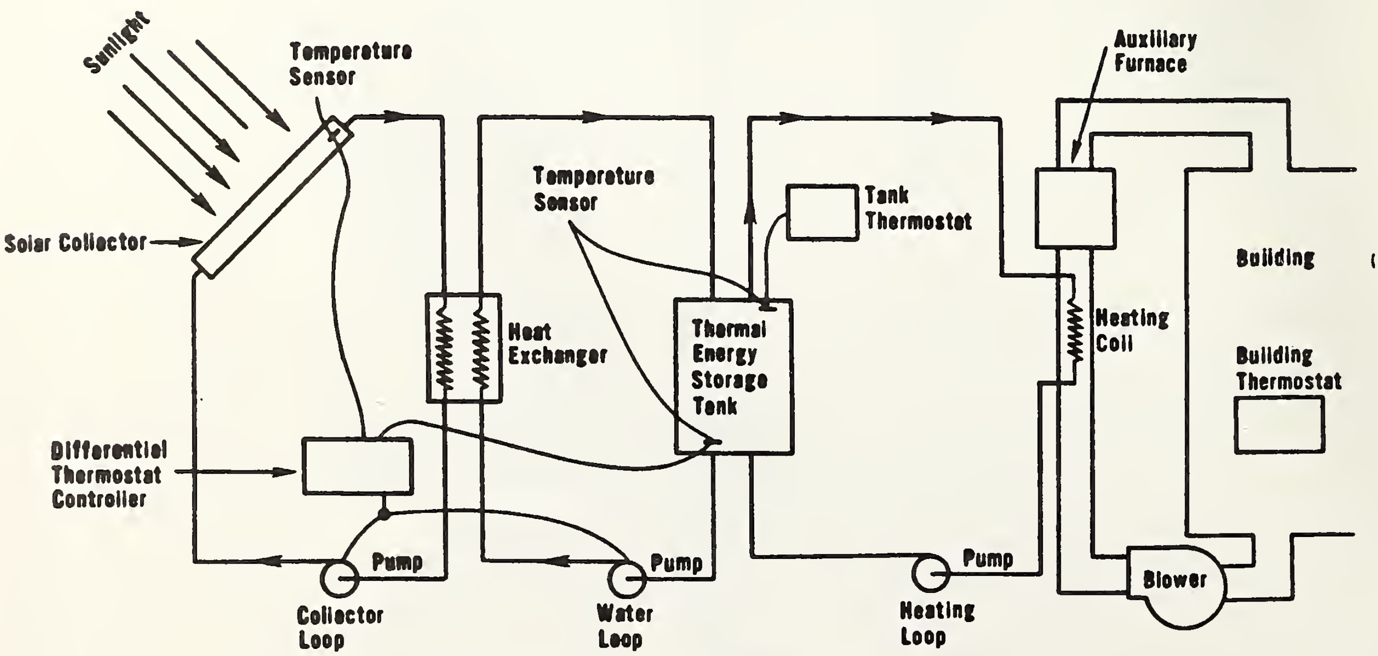
One of the most important elements in evaluating the suitability of a building for proposed solar retrofit is available space. In addition to the solar collectors on the roof, considerably space is needed for auxiliary equipment, some of which is both large and heavy. The equipment required will depend upon the type of solar system being considered and its relationship to existing heating and air conditioning equipment. In particular, space will be required for heat storage units, pumps, air handlers, and heat exchangers.

The following figures no. 11-15 identify the kinds of equipment needed for only a few of the possible solar heat configurations which are in general use. Included is a schematic drawing of the operating modes for one type of heat collector system. Before deciding what specific space is needed for solar heating, it is important to consult with a competent solar system designer. The kinds and configuration of equipment chosen will vary between designers, and will be strongly influenced by the existing system and its components, the character of load, location of building, and other factors.



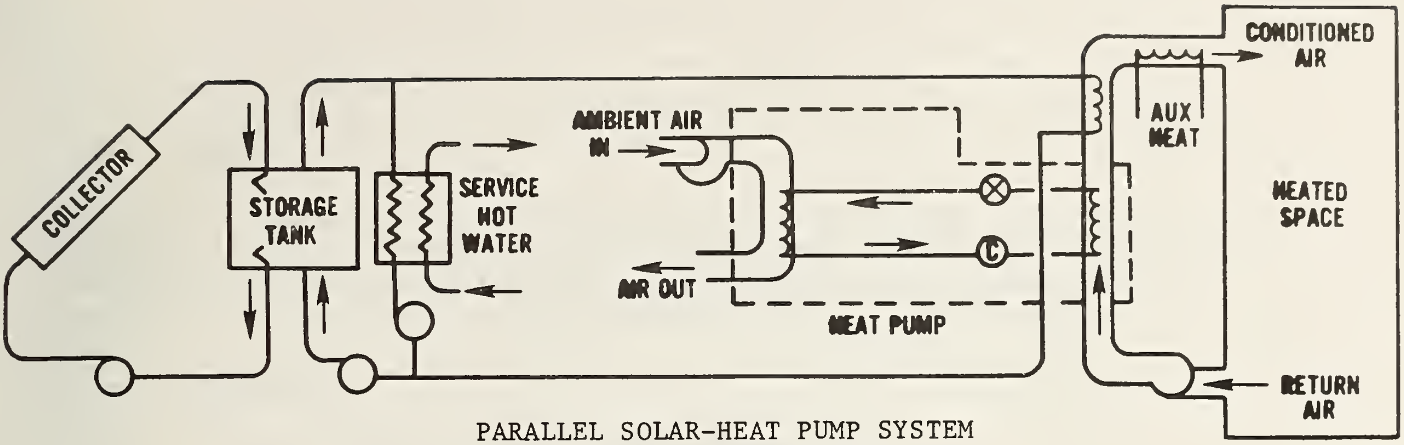
OPERATING MODES OF AIR TYPE SOLAR SYSTEM WITH ROCK BED STORAGE

FIGURE 11 [7]



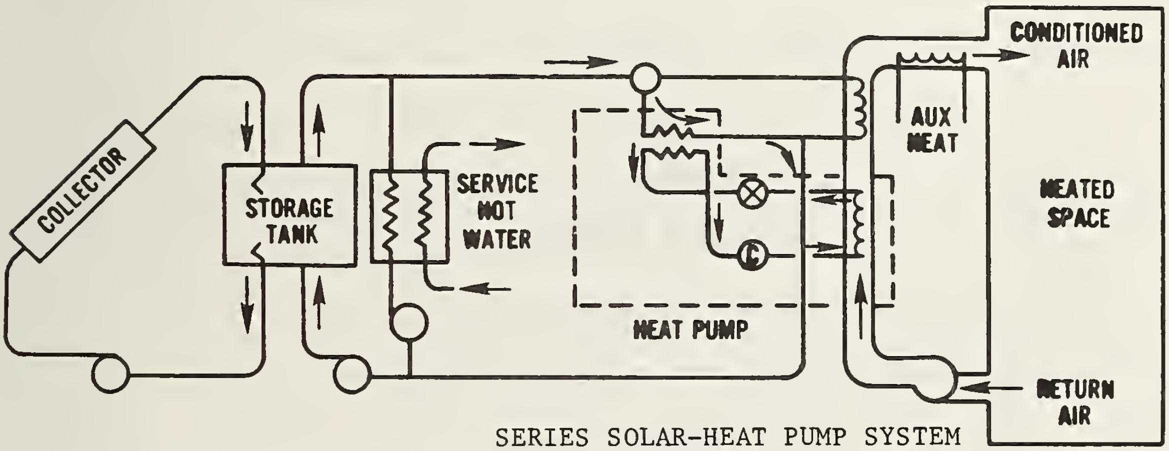
WATER-BASED SYSTEM WITH TANK STORAGE

FIGURE 12 [7]



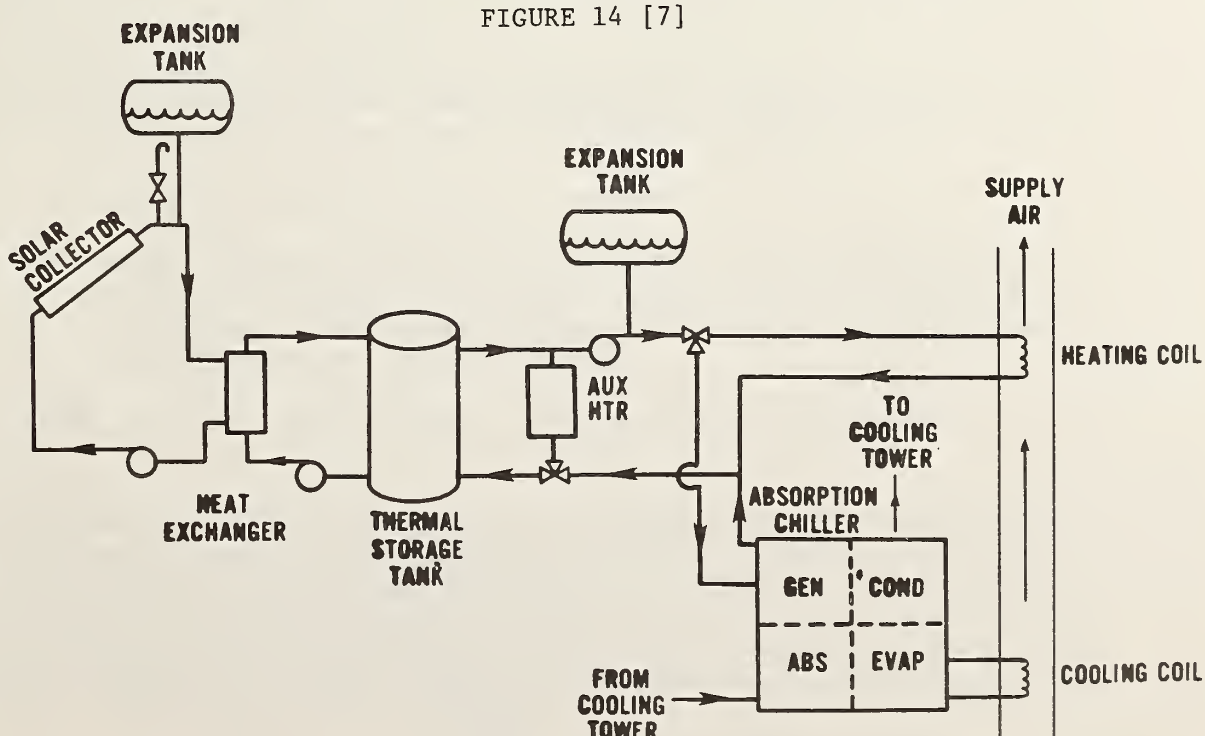
PARALLEL SOLAR-HEAT PUMP SYSTEM

FIGURE 13 [7]



SERIES SOLAR-HEAT PUMP SYSTEM

FIGURE 14 [7]



SOLAR ABSORPTION COOLING SYSTEM

FIGURE 15 [7]

APPENDIX D.6

Plumbing Systems

D.6 PLUMBING SYSTEMS

D.6.1 GENERAL

This section covers specific tests to be used for further evaluation of existing plumbing systems being considered for adaptation to solar retrofit. Instructions for visual inspection of the systems and a check list of potential problems were incorporated in section 5 of this report.

D.6.2 GUIDELINES

D.6.2.1 Test for Leaks in Water Supply System [38]

A simple method for checking on the presence of leaks in the water supply lines of the building follows:

1) Close the valves to all plumbing fixtures on the supply line.

2) Be sure the main water supply valve is fully open.

3) Listen for a gurgling or murmuring sound in the supply pipe. Hold a rod against the ear, and make contact with the other end of the rod at various points along the system, to pin point suspected leaks.

4) If no leak can be determined in any of the interior supply lines, and a leak still is suspected, listen for signs of leakage in the supply pipe leading from the water main outside the building. Also invite the water company to investigate their supply lines if gurgling or running water sounds persist.

D.6.2.2 Test of Supply Piping [38]

Clogged water supply pipes often cause a reduction in water pressure at the faucets. Adequacy of the pressure may be checked as follows:

1) Open top floor lavatory and sink faucets.

2) Open bathtub faucets and flush the toilets. If the flow of water in the top floor fixtures is reduced substantially, the piping may be of inadequate size or badly clogged with scale, assuming there is normal pressure at the water supply.

D.6.2.3 Water Test for Leaks in Drain, Waste and Vent (DWV) System [60, 61, 62]

A standing water test of the DWV system is a simple method for testing for leaks in the drain piping. A suitable plug can be inserted in the clean out at the lowest point of the system, and each water closet and P-trap can be plugged, thereby creating a closed DWV system. With at least a 10 foot head of standing water in the vent piping for 30 minutes or more, the DWV piping system can be checked for leaks to determine whether parts of the piping need

to be replaced. A partial inspection behind a wall may be made through suitable openings such as electrical wall outlets, or by removing the baseboard.

D.6.2.4 Air Test for Leaks in DWV System [61, 62, 63]

An alternate test for leakage in the DWV piping consists of plugging all terminals, including open vents in the system, and compressing the air in the system to at least 10" Hg (or 5 psi) for 15 minutes to see whether the system will hold the pressure. Leaks may be detected by listening for leaking air, or by using a soap bubble test.

D.6.2.5 Siphonage of Traps [64, 65, 66, 67, 68, 69, 70, 71, 72]

Where several plumbing fixtures are connected to a single horizontal drain, or a drain empties into a vertical stack which also carriers effluent from floors above, there exists the possibility that the movement of waste in the system will induce siphonage in the system (i.e., removal of the water seal from traps). Too little water remaining in a fixture trap may permit vermin or sewer gas entering the building through the trap.

In testing for siphonage, one or more fixtures are filled to overflowing and discharged. The remaining level of water in the trap seal of each fixture is then measured to determine the depth of seal retention. At least 50 percent or 25 mm (1 in) of the original seal depth should be retained in all fixtures. If excessive siphonage occurs, the drain lines and connections should be cleaned, enlarged, properly vented, or otherwise modified.

If an existing building is being considered for solar retrofit, the entire drainage system should be examined (and tested if necessary) under the supervision of experienced plumbing officials, to assure compliance with the health and safety requirements of the appropriate plumbing code.

APPENDIX D.7

Electrical Systems

D.7 ELECTRICAL SYSTEMS

D.7.1 GENERAL

Section 6 of this report covered the preliminary evaluation of existing electrical systems, and consisted primarily of visual inspection of the systems. This section includes actual tests to be performed on the systems, utilizing instruments. Consequently, experience with certain high voltage instruments, and a greater amount of time and judgment will be required.

D.7.2 GUIDELINES

D.7.2.1 Megohm Test (Megger Tester) for Electrical Insulation [38, 73]

If the insulation appears to be deteriorated (crumbling or cracking), it is always best to replace the wiring. If there is a question regarding the adequacy of the insulation, the megohm test may be used to check it. In this test, the wires for each circuit are disconnected at the power supply, and a "Megger" tester is used to apply test voltages to the branch circuits. Branch circuits should read at least one megohm to ground. If lights or appliances are included in the branch circuit, readings should exceed 500,000 ohms. (Feeders should be tested in accordance with Article 110-20 of the National Electrical Code.) If there are any low resistance readings or indications of shorts in the circuit, the insulation is considered faulty, and the circuit wiring should be replaced. Because high voltages are used and experienced judgment is needed, only a qualified electrician should perform the test.

D.7.2.2 Voltage Drop Determination [74]

The measure of voltage drop in a branch circuit under normal load is a good indicator of excessive impedance (e.g., excessive length) of the circuits. Conductors in branch circuits will perform more efficiently if the following conditions are met:

1) The voltage drop at the farthest outlet for power, heating and lighting loads does not exceed 3 percent.

2) The maximum total voltage drop in feeders and branch circuits to the farthest outlet does not exceed 5 percent.

If voltage drops are much in excess of these values, the circuit needs replacement. Generally, ordinary voltmeters may be used for determining voltage drops in the circuits. Because measurements must be made under load (with the current also being measured) only a qualified person should undertake the tests.

D.7.2.3 Circuit Analyzer for Circuit Faults [75]

A commercially available electrical analyzer is available to determine various faults in existing wiring systems. It was originally developed for testing

newly wired circuits, but it also may be used for assessing performance of existing systems. The circuit analyzer will check the following circuit conditions:

1) Open ground
2) Open hot
3) Open neutral
4) Hot/ground reversed
5) Hot/neutral reversed

Measurements obtained will indicate only design or operating faults such as improper connections. The analyzer will not determine the condition of the materials which make up the branch circuit. The manufacturer's instructions must be followed in using the analyzer and interpreting the readings, and only a qualified person should conduct the tests. The analyzer can be used on two-wire circuits by utilizing a special adapter.

D.7.2.4 Circuit Breaker and Resistance Tester [76]

A commercial circuit breaker and resistance tester is available also for evaluating circuit breakers by simulating an overload condition as a proof test of the circuit breaker. A special component comes with the instrument which may be used for evaluating resistance of windings (and other equipment resistances) in the range of 1 megohm to 1000 megohms. The current is limited to five milliamperes for maximum safety. The resistance tester is intended to indicate potential breakdown in electrical resistance of insulating materials.

Circuit breakers are tested with the breaker removed from the panel. If there is no master disconnect, the utility company should be asked to cut off service during removal of the breaker. Only a qualified electrician should be engaged to conduct the tests.

NBS-114A (REV. 2-8C)

U.S. DEPT. OF COMM. BIBLIOGRAPHIC DATA SHEET (See instructions)	1. PUBLICATION OR REPORT NO.	2. Performing Organ. Report No.	3. Publication Date
	NBSIR 81-2289		July 1981

4. TITLE AND SUBTITLE

Preliminary Guidelines for Condition Assessment of Buildings Being Considered for Solar Retrofit

5. AUTHOR(S)

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6. PERFORMING ORGANIZATION *(If joint or other than NBS, see instructions)*

NATIONAL BUREAU OF STANDARDS
DEPARTMENT OF COMMERCE
WASHINGTON, D.C. 20234

7. Contract/Grant No.

8. Type of Report & Period Covered

NBSIR/Final

9. SPONSORING ORGANIZATION NAME AND COMPLETE ADDRESS *(Street, City, State, ZIP)*

U.S. Department of Energy
Office of Solar Applications for Buildings
Office of the Assistant Secretary
Conservation and Renewable Energy
Washington, D.C. 20585

10. SUPPLEMENTARY NOTES

☐ Document describes a computer program; SF-185, FIPS Software Summary, is attached.

11. ABSTRACT *(A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here)*

This report was developed to help Federal agencies determine if buildings in their inventory are suitable for solar energy retrofit. It describes evaluation methods which are available to the facilities engineer to assist in determining whether the building and its systems (structural, HVAC, plumbing, and electrical) can be retrofitted with solar energy equipment under the Solar Federal Buildings Program (SFBP). Techniques for preliminary on-site inspection are emphasized, while more detailed evaluation techniques are described briefly and are referenced further.

The report describes evaluation methods available specifically for use with the structural materials of concrete, steel, masonry, and wood, as well as for use with the heating/ventilating/air conditioning, plumbing, and electrical supportive systems.

Comparative tables are provided for each building material to aid the reader in making a quick selection of the evaluation method most appropriate for the parameter to be tested. In addition, checklists are provided which identify common problems associated with each building material, possible causes of the problem, and the potential impact of the problem on the existing building systems and the solar retrofit system.

12. KEY WORDS *(Six to twelve entries; alphabetical order; capitalize only proper names; and separate key words by semicolons)*

Building rehabilitation; concrete; electrical; evaluation; HVAC; masonry; plumbing; steel; solar; structural systems; test methods; wood

13. AVAILABILITY

☒ Unlimited
☐ For Official Distribution. Do Not Release to NTIS
☐ Order From Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402.
☒ Order From National Technical Information Service (NTIS), Springfield, VA. 22161

14. NO. OF PRINTED PAGES

138

15. Price